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Research and Technology

Annual Report 1985

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Houston, Texas

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Research and Technology

Annual Report 1985

December 1985

Prepared by
Office of the Director of Research and Engineering
Lyndon B. Johnson Space Center
Houston, Texas

Preface

This report is prepared on an annual basis for the purposes of highlighting the fiscal year research and technology (R&T) activities. Its intent is to better inform the R&T Program Managers of significant accomplishments that promise practical and beneficial program application. The report is not inclusive of all R&T activities. This document will be updated in November of each year.

The JSC Annual R&T Report is compiled by the Office of the Director of Research and Engineering. The personnel listed below have coordinated the technical inputs for their respective sections of the report. Detailed questions may be directed to them or to the technical monitors listed in the Significant Task indices.

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Aeronautics and Space Technology

Summary

Office of Aeronautics and Space Technology

Summary

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In fiscal year (FY) 1985, the Lyndon B. Johnson Space Center (JSC) conducted a variety of technology development activities under the sponsorship of the Office of Aeronautics and Space Technology (OAST). These activities were sponsored by the Space Research and Technology (R&T) Base Program (UPN 506), the Space Flight Systems Technology Program (UPN 542), and the Space Station Focused Technology Program (UPN 482). The Aeronautics Program (UPN 505) also provided complementary funding to the Space R&T Base Program in the area of advanced information systems technology.

Although certain projects were moved from the Space R&T Base to the Focused Technology Program in FY 1985, the essential content of the R&T Base Program remains unchanged from previous years and incorporates those areas of technology development in which JSC personnel have particular expertise gained through the development and operation of NASA's manned spaceflight programs. Significant activities are continuing in advanced information and electronic systems, energy conversion systems, vehicle controls technology, advanced life support and extravehicular activity (EVA) systems, human factors technology as it relates to man/machine system interfaces, and transportation systems R&T. A modest effort is also continuing in aerothermodynamic analysis of surface catalysis effects as it relates to aerobraking orbital transfer vehicle (AOTV) technology.

The Focused Technology Program, specifically directed at achieving a state of technology readiness for the Space Station, complements many of the more generic activities in the R&T

Base Program and additionally includes efforts in space communications and space power systems.

The following paragraphs summarize the work being accomplished in the major technology areas. Reports on selected tasks follow the summary.

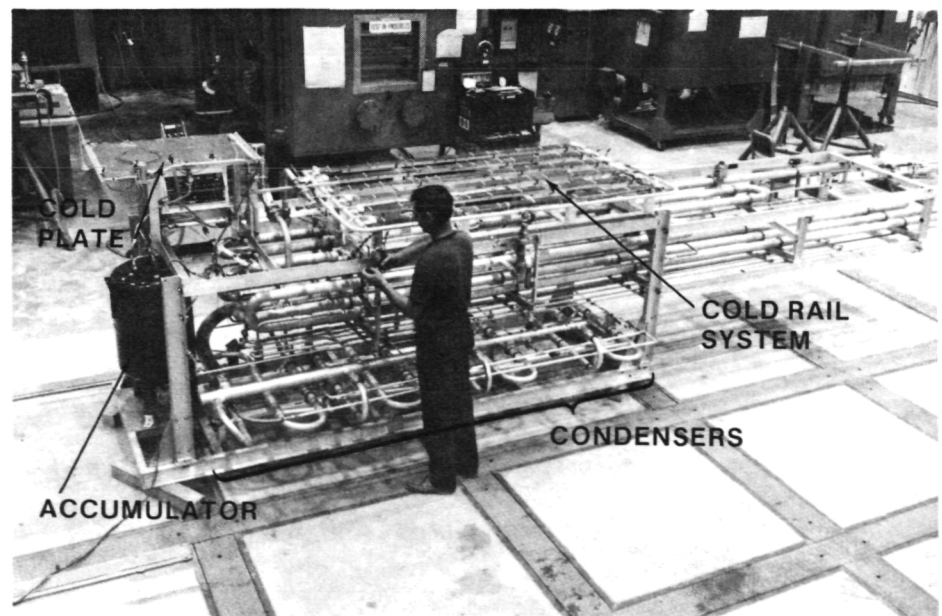
Thermal and Power Systems R&T

The two programs in the thermal and power systems R&T area are: (1) thermal management of large spacecraft systems and (2) regenerative fuel cell technology. The thermal management work is developing the needed technology for efficient thermal acquisition, transport, and rejection for large power systems of multihundreds of kilowatts. The concept is to develop a system that is much like a public utility which can be easily expanded and

adapted to accommodate increasing customer needs. Central to this concept is the development of a two-phase (liquid/gas) thermal transport loop described in a later article. The accompanying illustration shows a system-level technology demonstrator undergoing tests at JSC. An integral part of this program is the development of a modular space-constructible heat pipe radiator for thermal rejection. A 50-ft prototype radiator element has recently undergone qualification testing in JSC's Chamber A thermal vacuum facility. The radiator element will be flown on the Space Shuttle as a flight experiment in 1986.

Regenerative fuel cell technology, conducted in cooperation with the NASA Lewis Research Center, is progressing towards the development and testing of a 10-kW Space Station prototype

Technology demonstrator thermal bus system test article.



system. The complete system, shown schematically in the illustration, should be ready for testing in the latter part of 1987.

Human Factors and Habitability Systems R&T

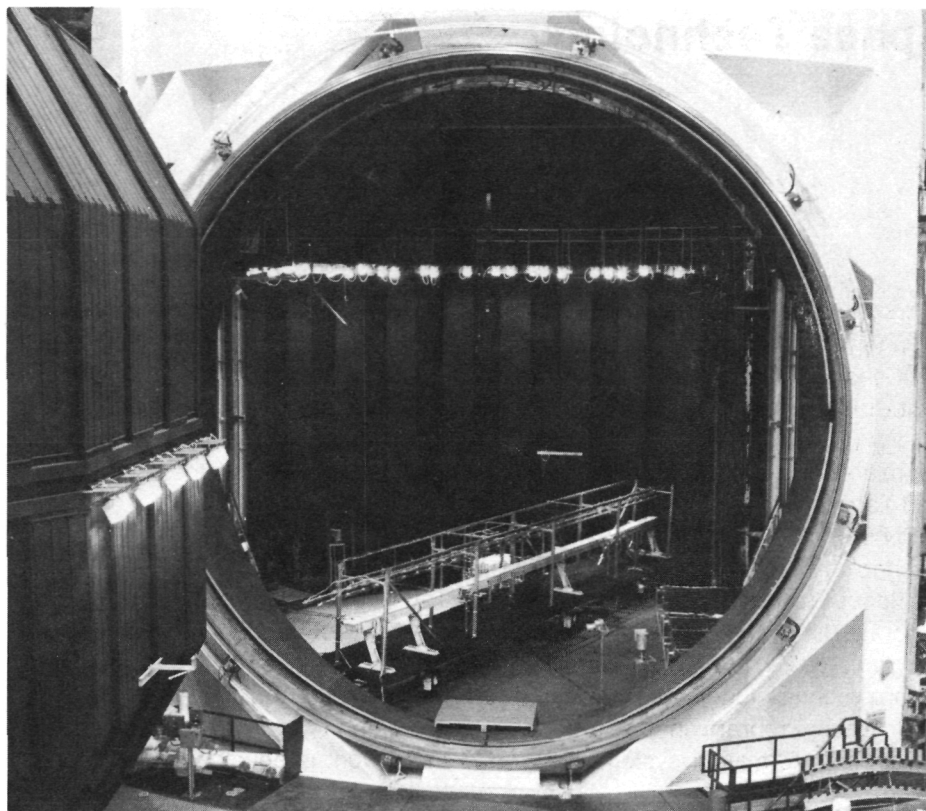
Several aspects of human factors and habitability technology are being pursued at JSC with the objective of ensuring maximum crew productivity and spacecraft livability. Many concepts describe how an astronaut should fit into his or her workplace and interact with it; for comfortable, efficient, and safe working conditions, certain standards must be maintained. Such standards, guidelines, and specifications are spread through a large number of documents, and other valuable data exist in research literature and in unpublished form. The JSC has initiated a project that will collect, organize, review, and critique all available data related to interface design standards. This project, worked in cooperation with experts in the field from both government and industry, will culminate in a set of standards for future spacecraft that has been reviewed and approved by the human factors design community.

Other related man/machine interface projects include the development of computerized anthropometric models which can be used in computer-aided design (CAD) systems for rapid design and evaluation of work station concepts, crew task planning, and a variety of other man/machine system investigations. Advanced display and controls technologies are being developed and evaluated to provide efficient interfaces to minimize crew workloads. Later articles describe these activities in detail.

Architectural concepts for crew work and living areas are being evaluated via a set of full-scale mockups of Space Station habitability modules such as shown in the illustration. As the program progresses, functional subsystems with which the crew must interface will be incorporated and

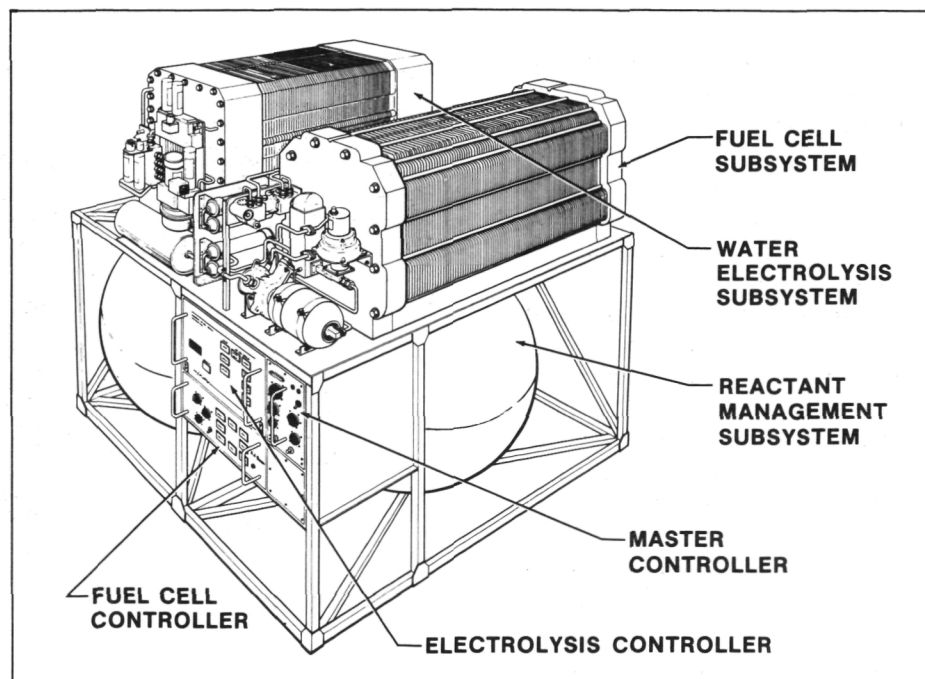
evaluated in the mockups. One such subsystem now under development,

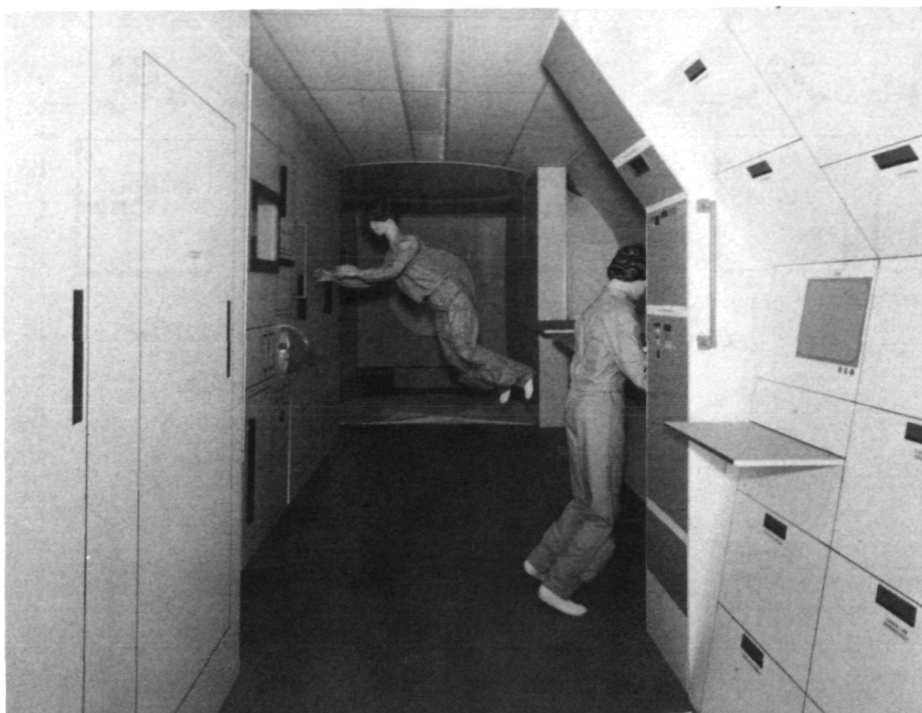
a zero-g whole-body shower, is described in a later article.



A 50-ft prototype radiator element prepared for testing in JSC's thermal vacuum facility.

Regenerative fuel cell Space Station prototype.





Interior view of full-scale Space Station module used to evaluate candidate habitability architectures.

Advanced Life Support and EVA Systems R&T

For several years, the JSC has been engaged in the development of subsystem technology for advanced regenerative life support systems. Regeneration refers to the collection, processing, and recovery of the constituents in the air and water systems such that they operate in a closed loop, thereby minimizing resupply weight and costs. The illustration shows schematically a regenerative system as is envisioned for use on a fully operational Space Station. Subsystem technology development has concentrated on carbon dioxide removal (for both cabin and EVA systems), oxygen generation, and instrumentation subsystems required for monitoring oxygen and water quality to maintain safe standards. A later article describes a static feedwater electrolysis technique being developed for oxygen generation.

The preprototype subsystems that have been developed are being integrated into a system-level configuration and installed in a JSC 20-ft vacuum

chamber for "closed door" testing. These will be replaced with upgraded prototype subsystems now under development to support manned chamber testing of the complete regenerative system.

The major activity in the area of EVA systems is supporting the development of an advanced extravehicular mobility unit (EMU) prototype system. Because the advanced system will likely operate at a higher pressure than does the current Space Shuttle EMU, or space suit, mobility characteristics must be improved. The current technology program, being conducted in association with personnel of the NASA Ames Research Center, is developing a new joint configuration for testing in a previously developed high-pressure suit. The upgraded suit system is anticipated to be available for water immersion facility (zero-g simulation) testing in mid 1987.

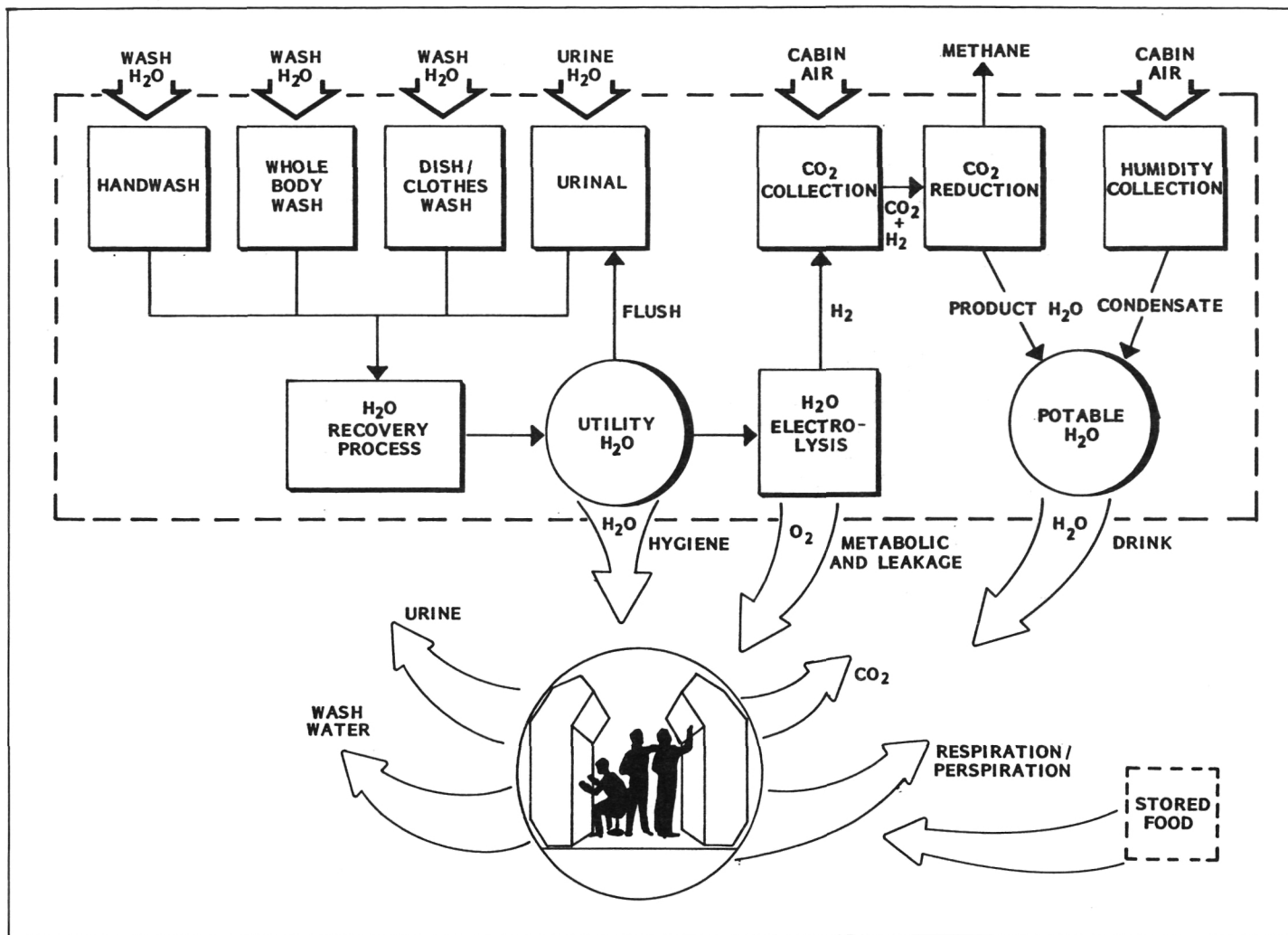
Two additional EVA systems activities are directed at the problem of easing the astronaut's EVA task. An identified problem during EVA is that of hand fatigue caused by gripping

and holding actions while wearing pressurized gloves. As a partial solution to this problem, a power-assisted glove end effector is being developed. Various sensor and feedback techniques, which can be integrated with a generic power tool, are being investigated. A prototype system is expected to be completed by mid-1986. The second activity is that of design studies and development of a generic EVA work station. The goal is to develop a work station that is easily set up, can be maneuvered to maximize work activity, and can be used at unprepared as well as prepared work sites. A candidate design was tested in the JSC water immersion facility during FY 1985. Design improvements are being incorporated, and additional testing will continue into FY 1986.

Information and Data Management Systems R&T

Information and data management systems technology represents a major portion of the OAST-sponsored programs at the JSC, incorporating a variety of projects. The advanced information processing system (AIPS) project, supported by both the OAST space and aeronautics programs, has as its objective the development and demonstration of a system architecture with associated design and evaluation methodologies to provide advanced information system processing across a broad spectrum of applications. The system architecture, developed around fault-tolerant computer building blocks for subsystem- and system-level fault tolerance, emphasizes core data processing requirements and adaptability to a variety of applications. The AIPS, including its software environments using the Ada programming language, has been sufficiently demonstrated to be selected for implementation on the NASA oblique-wing experimental aircraft.

The JSC is the responsible center for the Space Station Program's data management system (DMS) advanced development, or testbed, program. The



Regenerative life support system.

OAST Focused Technology Program is supporting this activity in the area of the development of the network operating system (NOS) associated with the DMS. In FY 1985, a nucleus of the DMS was put in place to support the functional integration of other system testbeds under development at JSC. These other testbeds, located in physically remote facilities, communicate with the DMS through a commercial distribution system utilizing fiber optic buses. The communications interfaces are via bus interface units developed under OAST sponsorship in previous years.

The Space Station data system architecture study, initiated in FY 1985, has completed three of the five major tasks. Results of the completed tasks — covering system tradeoff studies, system options development, and initial

operational configuration (IOC) system definition — have been presented to other NASA centers and phase B contractors. A special review for interested NASA Deputy Associate Administrators was held in October 1985.

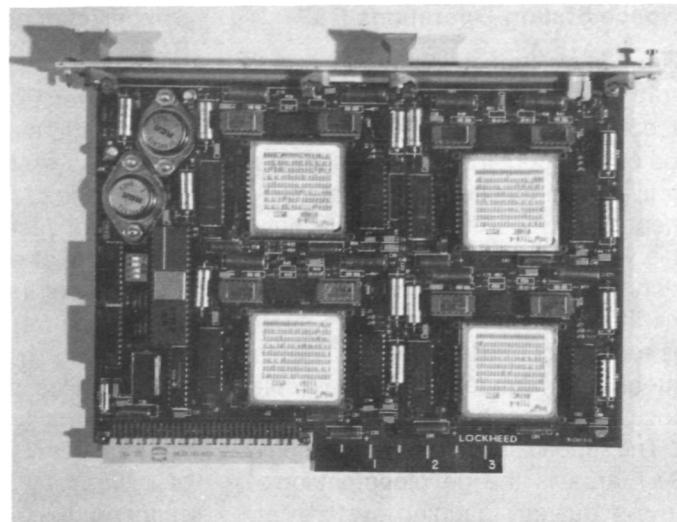
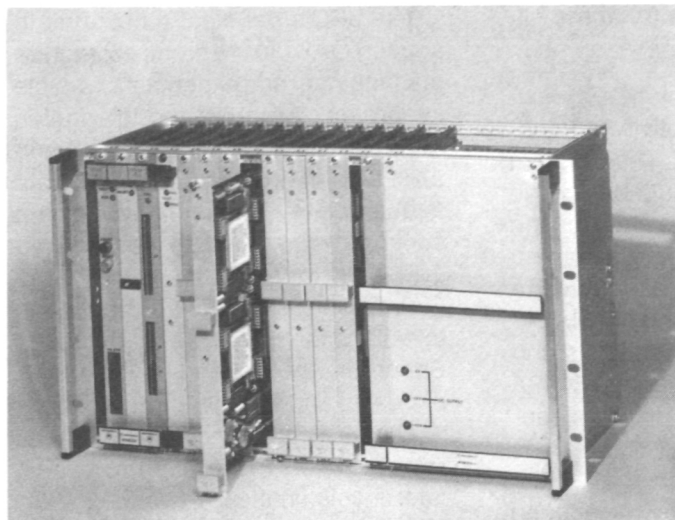
An ancillary project to the Space Station DMS work is the development of automated subsystem technology. Work has been in progress at JSC to develop a generic automation system and to demonstrate its capabilities using both mathematical model simulators and actual hardware components of the air revitalization loop of the regenerative life support system discussed earlier. Demonstration testing is scheduled to begin in early FY 1986.

The magnetic bubble memory system development was originally initiated as a potential replacement for the Space

Shuttle Orbiter's mass memory unit (MMU). It has continued with the fabrication of a 16-megabyte unit built with high-density 4-megabit devices. The accompanying illustration shows the physical configuration. The system will serve as an MMU simulator in the JSC avionics laboratory with the potential of being integrated into the Space Station DMS testbed.

Optical information processing activities have concentrated on the development of programmable mask technology. This work is described in a later article.

The JSC is also continuing as a Beta Test Site in support of the Department of Defense's Ada programming language development and implementation. A more detailed description of this activity appears in a later article.



A 16-megabyte bubble memory system (left) employs eight circuit boards (right) each containing four high-density 4-megabit memory devices.

Advanced Spacecraft Control Systems R&T

Controls technology work has been concentrated in two areas: (1) the development of an advanced on-orbit digital autopilot for spacecraft and (2) the development of a typical flight control design that is more adaptable to changes in configuration mass properties and uncertainties in both configuration parameters and the external environment. Both of these projects, described in detail in later articles, are products of the knowledge and experience gained in the design, development, and operation of the Space Shuttle Orbiter's on-orbit flight control system.

Communication and Tracking Systems R&T

The Focused Technology Program is supporting technology development activities in Space Station communications and tracking systems as a means of minimizing system developmental and operational costs while providing a system with the necessary operational flexibility and growth capability. Current efforts include various

aspects of antenna design for near- and far-range requirements, radio frequency (RF) multiaccess systems for multiple users, laser docking sensor work, television system technology, and signal design and processing techniques.

Structures and Materials R&T

Space Station configuration concepts now under evaluation employ large truss structures in the form of masts or planar arrays. The JSC has been pursuing the design of such a structural configuration known as the tetrahedral truss which can be folded and efficiently packaged for transportation to orbit, where it is automatically deployed and erected. Scale models have been fabricated and demonstrated in the JSC structures laboratory. Efforts are now focused on manufacturing methods and, as a part of this activity, a full-scale tetrahedral truss cell will be fabricated for further laboratory evaluation.

Materials technology projects are concerned with investigations of environmental effects on materials. The JSC is continuing to participate in a

NASA-wide program investigating the interaction of atomic oxygen on space materials. Several flight experiments have already been conducted during earlier Space Shuttle missions. A future experiment, evaluation of oxygen interactions with materials (EOIM 3) is now under development with international participation and has been accepted for flight assignment in early 1987.

With the advent of a permanent Space Station in low Earth orbit, damage caused by impacts from micrometeorites or even manmade debris is of increasing concern. The JSC has been investigating this problem in its hypervelocity impact facility. The facility has recently acquired a state-of-the-art camera with a frame rate capability of 2 million frames/sec. This system will permit detailed visual evaluation of the impact and damage mechanism. In addition to laboratory experimentation, analytical work has provided a computerized math model for predicting impact damage to composite panels. The model is still in a preliminary development stage and requires verification with experimental techniques.

Space Station Operations R&T

The Space Station operations R&T area is composed of two projects. The accompanying illustration summarizes the current construction and docking activities. In addition to the development of analytical docking simulations, this year's effort has focused on the technology development of system mechanisms and components such as sensors, controllers, and actuators/attenuators required to provide a soft docking and berthing capability.

The second project in the operations R&T area is the development of a zero-g quantity gauging system for cryogenic fluids. This project, newly initiated, will design and fabricate a system selected from a variety of concepts to be studied. Following laboratory and zero-g aircraft evaluation, it will be integrated into NASA's Cryogenic Fluid Management Facility flight experiment.

Space Transportation Systems R&T

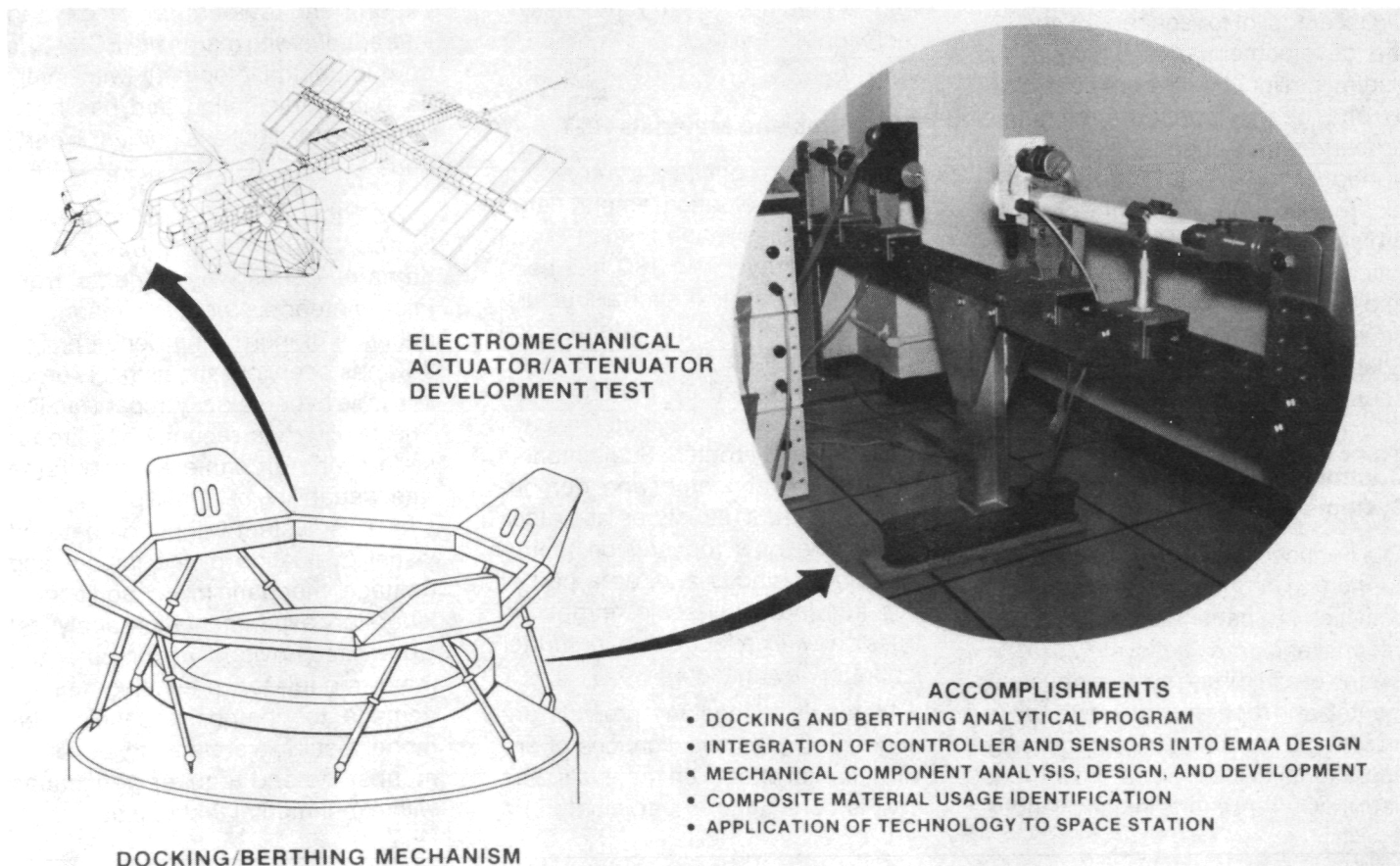
The Orbiter Experiments (OEX) Program is JSC's major activity in transportation systems R&T. The program objective is to use the Space Shuttle as a flight research vehicle for the acquisition of experimental data that will augment the R&T base for future space vehicle design. The NASA-wide program is structured to support technologists at the various NASA centers in developing flight experiments relevant to their particular areas of research. A number of OEX-sponsored experiments have been flown on Space Shuttle missions. Three major new experiments — the Shuttle infrared leeside temperature sensing (SILTS), Shuttle entry air data system (SEADS), and Shuttle upper atmosphere mass spectrometer (SUMS) — have been installed in the Orbiter *Columbia* and are scheduled to fly on an early FY 1986 mission.

The JSC's principal function is to support OAST in the areas of program management and experiment/vehicle integration. A part of the integration responsibility is to ensure the availability of instrumentation and data acquisition systems for experiment support. A later article describes a JSC-developed data system, the OASIS, which will acquire information to expand the data base relative to the Space Shuttle payload bay dynamic, acoustic, and thermal environment.

The JSC personnel also act as experimenters in the OEX Program. A later article entitled "Advanced Autopilot for Spacecraft" reports on the OEX-sponsored development and flight demonstration of a more efficient on-orbit digital autopilot for the Space Shuttle Orbiter and other spacecraft.

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Construction and docking technology will develop a soft docking and berthing capability for Space Station assembly and operations.



Aeronautics and Space Technology

Significant Tasks

Thermal Management for On-Orbit Energy Systems

TM: J. Gary Rankin/EC2
Reference OAST 1

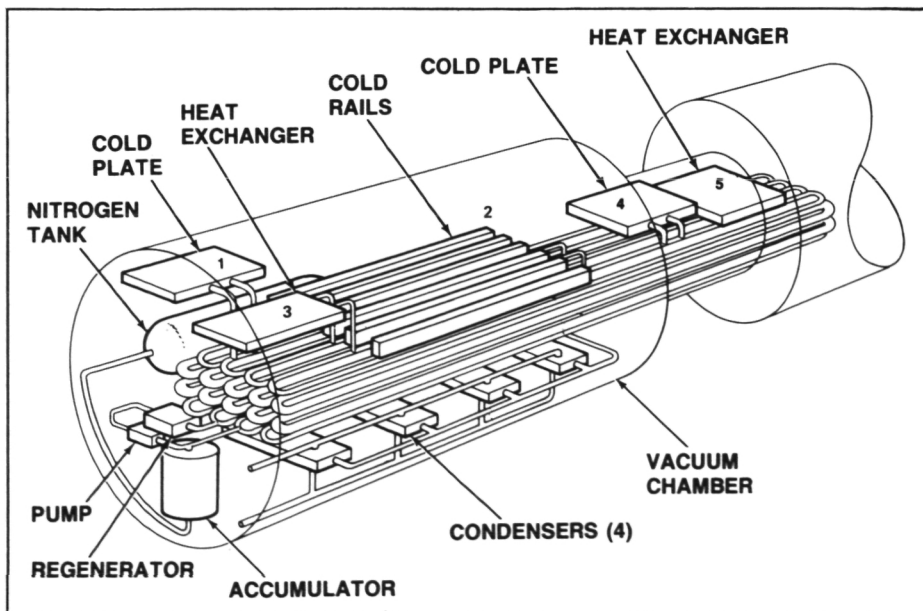
Manned and unmanned space platforms projected for the 1990's and later may produce electrical power levels of several hundred kilowatts. Efficient thermal management is mandatory because generation, transfer, and storage of the electrical energy needed for these applications will require the dissipation of huge quantities of waste heat. No low-cost, reliable orbital thermal management system capable of providing this level of heat rejection exists. Such a system would need to overcome limitations inherent in current system designs. Ways to increase energy capacity, reject waste heat, and provide power for a broad range of space applications necessitate an entirely new technical concept in thermal management.

The key to the thermal management concept lies in the creation of a thermal utility system, analogous to municipal public utilities, where basic trunk lines are provided and into which individual customers can be integrated. The system must be designed such that changes in location or load of individual customers have minimal effect on the utility's capability to serve the loads of the remaining customers. Such a centralized system would allow reduced operational and payload integration costs, as well as reduced cost for all payload users, by having common instrument thermal designs. Keys to reduction in thermal management system costs include system modularity; subsystems integration; growth capability to very large satellites; volume and weight reduction; extended life by maintenance and replacement; and expansion of the thermal management technology base to provide simpler, more reliable systems.

To meet these requirements, concepts involving two-phase (gas/liquid) heat transport devices are being developed. A centralized, pump-assisted two-phase heat transport loop (or "thermal bus") would transfer heat by evaporation and condensation of the working fluid rather than by sensible heat changes of a single-phase cooling fluid. This loop would operate at an almost constant temperature over its entire length, making users unaffected by their order of placement around the loop. Such a thermal bus would also be capable of transporting large thermal loads over long distances with pumping requirements that are minimal compared to single-phase systems.

A design has been completed for a complete 25-kW pumped, two-phase, thermal bus system. This system contains five separate evaporators of different types, each capable of accepting up to 5 kW of heat. Four separate but identical condensers provide the heat sink for the thermal bus by allowing a contact interface with either simulated or actual high-capacity heat pipe radiator elements. Fifty meters of both vapor and liquid transport lines are included to be representative of Space Station dimensions. Several of the evaporators have been successfully tested at the component level using Freon-11 as the working fluid. The system-level test article, shown in the figure, has been fabricated, assembled, and tested with all components except three of the individual evaporators. These evaporators will be added to the system at the NASA Johnson Space Center, where extensive ambient and thermal vacuum performance testing with both Freon and ammonia will be conducted.

Physical layout of the 25-kW thermal bus test article.



Advanced Radiator Flight Experiment

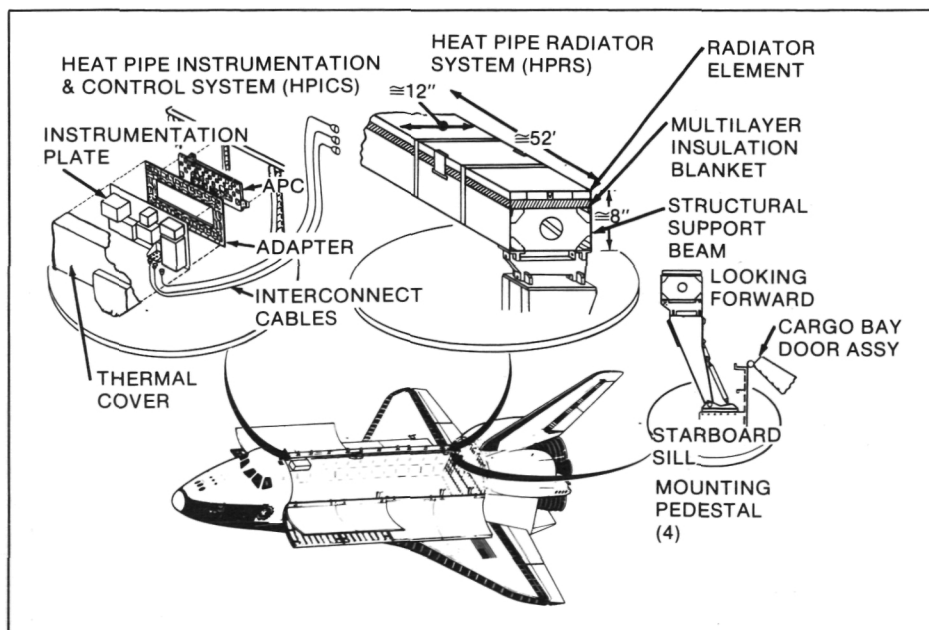
TM: J. Gary Rankin/EC2
Reference OAST 2

Unique requirements imposed by the Space Station — such as high heat loads, long transport distances, on-orbit assembly and maintenance, and long operating life — have created the need for technology development in heat rejection. Since 1979, the Johnson Space Center (JSC) has been conducting a program to develop a modular heat pipe radiator subsystem for Space Station application. The major thrust of the technology program to date has been to improve heat pipe capacities to accommodate the radiator application. Performance capabilities of the baseline heat pipe design were successfully demonstrated in laboratory tests, KC-135 zero-g tests, and a Space Shuttle on-orbit flight experiment of a small element. Additionally, two full-size prototype radiator elements were fabricated and tested in JSC thermal vacuum facilities.

The next step in the development of this space-constructible heat pipe radiator system will be the demonstration of the thermal performance of a representative full-size radiator element as a Space Shuttle flight experiment. This experiment, designated SHARE (Space Station heat pipe advanced radiator element), will consist of a 52-ft radiator element containing a full-length, high-capacity monogroove heat pipe condenser surrounded by a simplified monocoque-design radiating fin. The 2-ft, six-legged monogroove heat pipe evaporator will be electrically heated with up to 2 kW of heat to simulate Space Station thermal loads. The radiator element will be supported by a specially designed structural beam and four pedestals to allow packaging in the volume reserved for the Space Shuttle starboard remote manipulator system. Heater control and data processing will be done with a separate heat pipe instrumentation and control system mounted along the starboard sill in the Orbiter's payload bay.

All flight hardware has been fabricated, and a system-level thermal vacuum qualification test was completed at JSC in September 1985. The expected flight date for the SHARE is June 1986.

The SHARE flight element configuration as it will be installed in the Orbiter payload bay.



Crew Station Human Factors

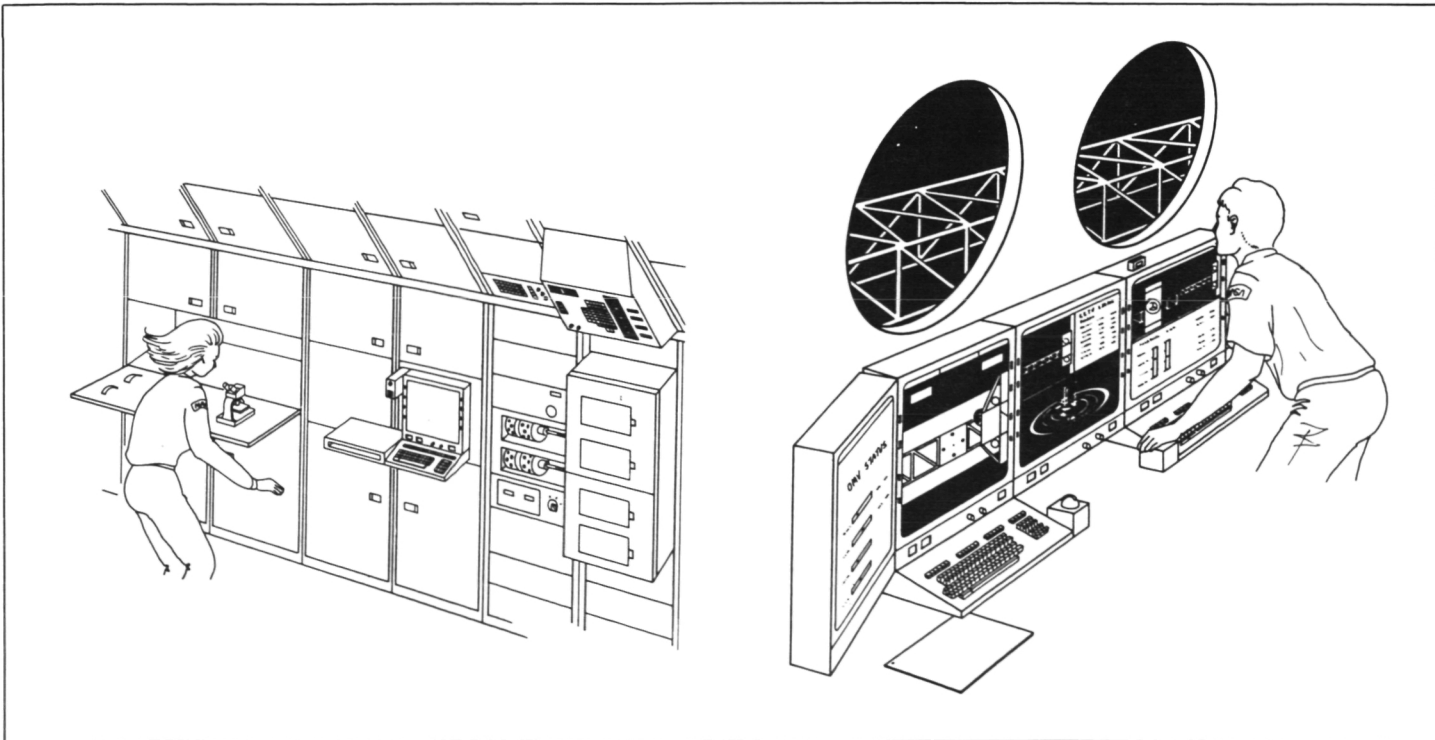
TM: Marianne Rudisill/SP22
Reference OAST 3

Advances in display, control, and user/computer interaction (UCI) technologies have been rapid, and several of these advanced technologies have been incorporated into aircraft cockpits. These technologies — such as voice recognition and synthesis, high-resolution color graphics, and multifunctional displays and controls — have been used to reduce operator workload, to enhance information transfer between operator and computer systems, and to support the crewmember in several roles. These rapid advances provide great promise for future space applications such as the permanently manned Space Station. They have, however, occurred so quickly that they have left gaps in our understanding of the way in which these technologies may be used in the space environment.

To understand these techniques better, researchers at the Johnson Space Center (JSC) have established a program to examine advanced display, control, and UCI technologies and to determine where and how they may be incorporated into space crew work stations to support the astronaut in the on-orbit conduct of crew activities. A matrix was created, identifying issues derived from the interaction between advanced technologies and user information needs. A research plan was developed from these issues and is presently being implemented. Typical UCI issues being examined are graphics for rendezvous and proximity operations, highlighting within display formats, six-degree-of-freedom manual control, use of multifunctional displays and controls, and windowing for user/computer dialog.

A human factors laboratory was established to provide a test environment for this program. Experiments are conducted to examine specific issues, and findings are incorporated into a work station designed to simulate on-orbit operations in essential aspects. Several on-orbit operations scenarios are presently being developed to support laboratory evaluations of display, control, and user/computer dialog concepts. Members of the astronaut team, mission operations personnel, and engineering personnel are active participants in these evaluations. The products of this program are guidelines for the incorporation of advanced technologies into space crew work stations and demonstrations of their uses in simulated on-orbit operations scenarios.

Advanced work station concepts.



Computerized Human Strength and Motion Modeling

TM: Barbara Woolford/SP22
Reference OAST 4

Computer models of human beings can be used to bring human factors to the forefront of the design effort. In the past, full-scale soft mockups have been used in the study and evaluation of the various human factor aspects of work station and habitat design. This approach can be costly and time-consuming in the preliminary design stages when a variety of concepts need exploration. The use of computer-aided design (CAD) systems, with the capability to model the human being, will revolutionize this preliminary design and evaluation process. The body can be placed at a work station, as shown in the illustration, where the man/machine fit can be evaluated by varying such characteristics as physical size, body stance, and limb reach and strength.

Research has been undertaken to develop modeling techniques for human strength and motion which can be used in interactive CAD systems. In conjunction with this development, techniques are being investigated to create the data base of human characteristics needed by the models

describing the total population of astronauts. Accomplishments to date include the development of a computer model used to create "Bubbleperson." This body, which has bendable joints and spine, is the most detailed model which the computerized system builds. The lengths of the body segments for the figure are automatically extracted from an anthropometric data base which is based on statistics collected from persons interviewed for astronaut candidate positions. The computer model, TEMPUS, positions the body in various poses automatically or with user inputs. For example, the figure can be commanded to reach a certain point in space with its left or right hand or foot, and will automatically assume a reasonable position for making this reach. The user may specify any joint angles by typing in the specific joint values or by positioning the setting of a potentiometer on the screen. The reachability of any point may be calculated by an automatic reach generation algorithm, described in "A Geometric Investigation of Reach," a doctoral dissertation by James Korein (1984). Alternatively, reach envelopes may be collected from actual people and graphically presented in the work station.

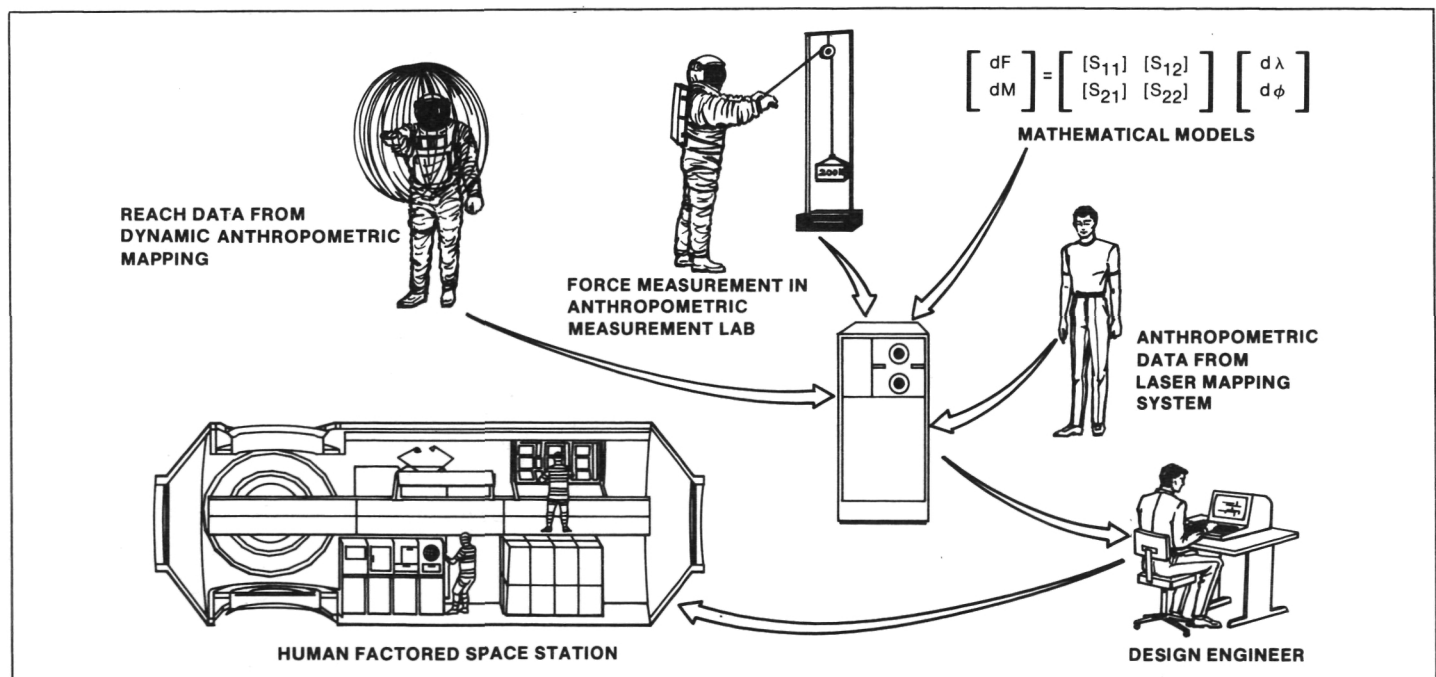
Additional data to expand the anthropometric data base will be collected

automatically during the coming year with the laser-based anthropometric mapping system. The software to calculate the coordinates of points on the surface of the human body has been developed and tested; work is underway to join multiple images to generate a total volume (front, back, and sides).

The first steps toward modeling human strength in this system have been taken. A review of literature describing state-of-the-art human force modeling from a muscular starting point has been performed. The alternative of modeling the body with a rotary motor at each joint is also being investigated. Data on single joint strength in zero-g as a function of position and restraint type will be collected on the Johnson Space Center's KC-135 zero-g aircraft during the coming year.

Additional data for the strength model will be extracted from films of extra-vehicular activities. In particular, the operations performed in large structure assemblies will be studied, and the biomechanics of the performance compared with that observed in the neutral buoyancy simulators.

Use of computerized human models in computer-aided design will significantly aid the human factors design and evaluation process.



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Zero-g Whole-Body Shower

TM: Rafael Garcia/SP23
Reference OAST 5

To date, all U.S. space programs except the Skylab Program have involved missions of short duration, with minimum provisions for personal hygiene and no specific provisions for a hygienic means of cleansing the whole body. Priorities and constraints of the Skylab Program prevented the optimization of a whole-body hygiene system. The United States is now fully committed to a permanent presence in space, thus establishing a requirement for such an optimized hygienic system to support future manned missions of long duration. A supporting research and development program is dedicated to providing a functionally verified whole-body shower in which hygienics and human engineering design concepts are optimized to meet the physiological, psychological, and social needs of crewmembers.

Activities are in process to redesign, modify, and test previously developed subsystem elements to optimize system performance and user compatibility. All technical information relating to whole-body hygiene that was generated from previous programs has been compiled, reviewed, and updated to incorporate the latest technological developments. Based on the final results of this research, a basic shower concept will be selected. A prototype will then be designed, fabricated, and functionally verified. Following verification of the prototype, flight demonstration hardware will be fabricated to verify the major subsystem elements functionally.

One configuration of the system has been assembled in the zero-g whole-body shower development laboratory at the Johnson Space Center (JSC). Operational and subjective testing and evaluation of the system, initiated in July 1985, will continue over a 6-month period. Currently, the research is focused on four aspects of the design: (1) biomedical, to ensure that factors which might endanger the safety of a crew are considered; (2) human engineering, to ensure that the design provides for optimum efficiency; (3) mechanical, to ensure that the most efficient, reliable, and maintainable subsystems are incorporated; and (4) electrical, to ensure efficient utilization of available power.

Phase 1 testing, using a vortex separator and a centrifugal separator, has been completed. The tests have provided data pertinent to the development of an optimized system. In the biomedical area, micro-organisms present in the system were isolated and classified. The resultant data will prove

beneficial in establishing the micro-organism growth rate within the shower system to help define a protocol for cleaning the whole-body shower. During the human engineering research, data were collected relating to the shower stall configuration, displays and controls, cleaning procedures, the amounts of water and cleansing agent used, and the time required to shower and to clean the shower stall. The mechanical evaluations provided data on relative humidity, drops in pressure, and changes in temperature and airflow, as well as on the overall efficiency of the system. The electrical research generated data on the characteristics (current versus time) and the power requirements of the electrical subsystems.

Tests are also in progress to evaluate the compatibility of the outputs from the shower system with water reclamation systems under evaluation for potential Space Station environmental control and life support subsystem usage.

Mechanical configuration of the whole-body shower system. The shower on the left is the Skylab system. That on the right is a functional prototype of the new system. Items on the equipment cart include the vortex and centrifugal separators.



Static Feedwater Electrolysis for Oxygen Generation

TM: Patrice S. Miller/EC3
Reference OAST 6

Space missions of longer duration will require an improved means for providing oxygen for crew breathing and cabin leakage aboard space vehicles. One possible technique for oxygen generation, water electrolysis utilizing a solid polymer electrolyte (SPE), has been under development since the early 1970's. Although previous water electrolysis subsystems incorporating SPE have demonstrated superior performance, extensive operation, and long shelf life, the weak link in the process has been the requirement for a dynamic phase separator/pump. As feedwater is supplied to the hydrogen compartment of the electrochemical cell, excess water exits with the hydrogen generated by the cell. A phase separator is used to free the hydrogen gas from the recirculated feedwater. The phase separator/pump has been proven by long-term tests to be a life-limited component. In addition, the lives of the electrolysis cells themselves are shortened by corrosion of the electrodes, promoted by their exposure to inorganic contaminants within the feedwater. In the past, multiple deionizer beds have been used to remove the inorganic contaminants prior to electrolysis.

Static feedwater electrolysis is being pursued as an improved oxygen generation technique. Development of a static-feed technique eliminates the need for any rotating components in the subsystem, representing a significant step toward hardware simplification. This technique also prevents the direct contact of liquid water and electrodes, thus extending cell life and minimizing the need for deionizer beds. Cells of this type were originally developed and tested for an Air Force satellite propulsion system.

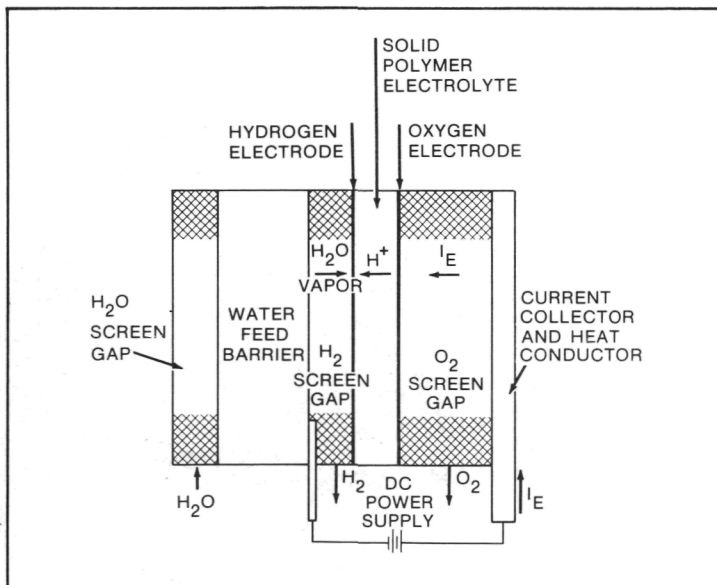
Rather than feeding directly into the hydrogen compartment of the cell, water is fed into separate, adjacent compartments. These compartments are separated by water feed barriers made of a material similar to that of the cell electrolyte membrane. Water vapor, but not liquid water, can pass through this barrier. With the application of direct current, electrolysis occurs at the cell electrodes, and oxygen and hydrogen are generated and exhausted without any free water.

The original static SPE feedwater electrolysis cells required a water pressure in excess of the hydrogen pressure to prevent buildup of hydrogen gas which would diffuse to the water side of the feed barrier membrane. A buildup of gaseous hydrogen would keep water from contacting the feed barrier, impeding the flow of water

vapor and eventually "starving" the cells of water, preventing electrolysis. To eliminate requirements for water-side pressure control, module design enhancements preventing hydrogen buildup were implemented. The additional cell features ensure that diffused hydrogen is continuously oxidized and that hydrogen is forced back into its own compartment. By electrochemically preventing the hydrogen from blocking the water feed to the cell, water can be supplied at ambient pressure.

A single static SPE feedwater electrolysis cell has been fabricated and tested. Successful performance was sufficiently demonstrated to justify the fabrication of additional cells, which were subsequently incorporated into a five-cell module with the capability to supply oxygen for approximately three men at a higher efficiency and with lower weight than previous designs. Module performance verification tests began in the Fall of 1985. Concurrently, a test stand to support further in-house testing at the Johnson Space Center is in the design phase. Integration of the module and test stand will occur in the Spring of 1986. Furthermore, additional single cells are to be constructed for use in comparative endurance testing for investigation of cyclic versus continuous operation.

Static SPE feedwater electrolysis cell schematic.



Power-Assisted Glove End Effector

TM: M. Lawson/EC2
Reference OAST 7

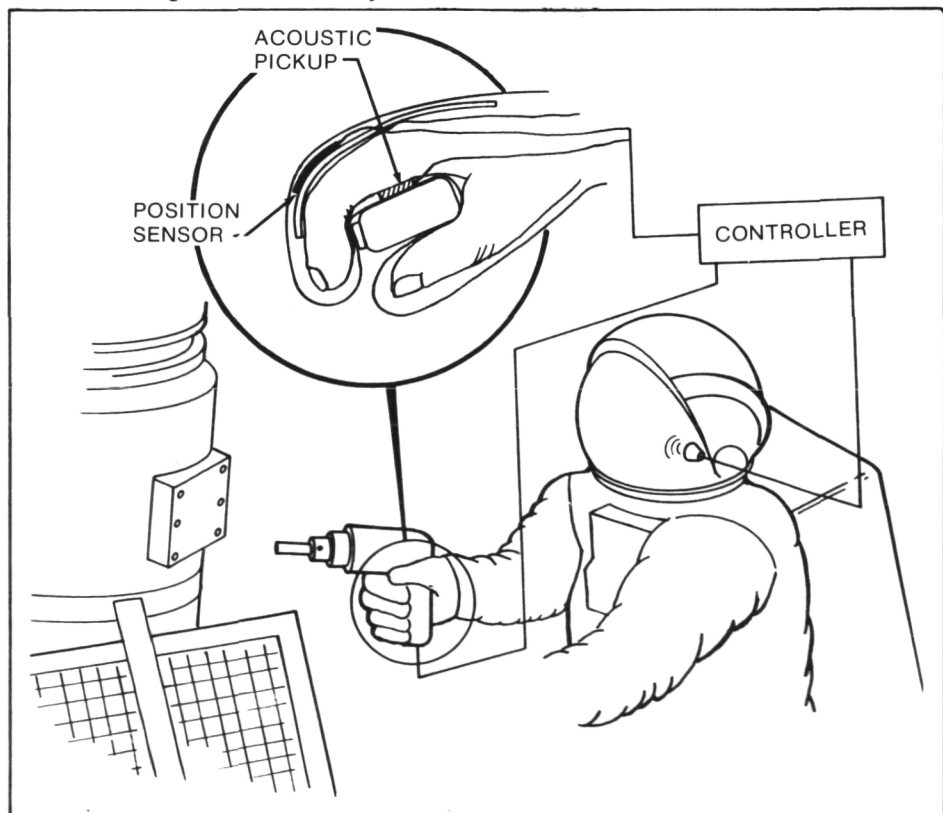
Extravehicular activity (EVA) by the Space Shuttle crews has shown a marked increase as increasingly complex satellite servicing and repair operations are attempted. Projections of Space Station activities indicate an even larger increase in the amount and complexity of EVA. One identified problem is excessive hand fatigue for the EVA astronaut, caused by the gripping and holding actions required while wearing pressurized gloves.

Work while wearing EVA gloves can be separated into three major components: delta pressure work, glove fabric work, and reaction force work. The Johnson Space Center power-assisted glove end effector program is a human factors program to integrate a generic power tool with a gloved human hand and minimize the hand fatigue.

The original concept was to enclose the hand inside a pressurized can to eliminate delta pressure work force. This technique did eliminate this force but did not address the glove fabric or the reaction force components. Designs proved to be quite bulky and created logistics and safety issues. The latest concept has evolved from promising work done in EVA glove technology. These new gloves can perform a task independently of the pressures to which they are pressurized (up to 8 psi). The concept is to install stress strips in the glove at points controlled by the crewmember, avoiding areas requiring large movement in the gloves. Strain gauges and piezoelectric sensors are being investigated as the power tool input devices. Piezoelectric strips can also be used as a sound feedback device providing the potential of audio indicators for the astronaut. Concepts have also been developed to reduce torque forces during bolt torquing.

Testing of piezoelectric devices has shown promise, but they have not yet been tested in a final configuration. Fabrication has started on the power tool, which will be capable of 5 ft-lb of torque with variable speed and reversible options. Completion of the project is expected in mid-1986.

Power-assisted gloves will ease many EVA tasks.



Programmable Mask Technology

TM: Richard Juday/EE6
Reference OAST 8

Until recently, information processing techniques for vision were based primarily on digital computers and numerical processing. The inherently parallel nature of optical information processing, coupled with the easy and natural optical Fourier transform and the programmable masks becoming available, can obviate numerical processing for a substantial number of problems. The masks are used to modulate the optical Fourier transform of an input scene; an optical retransform then allows direct detection of, for example, the mathematical correlation between the viewed scene and the reference image of the mask placed at the location of the optical Fourier transform. Thus, any image computation that can be cast in the form of a correlation (or equivalently, a convolution) between object and reference images is a candidate for optical processing.

Generic categories of problems that can benefit from optical information processing are pattern recognition and

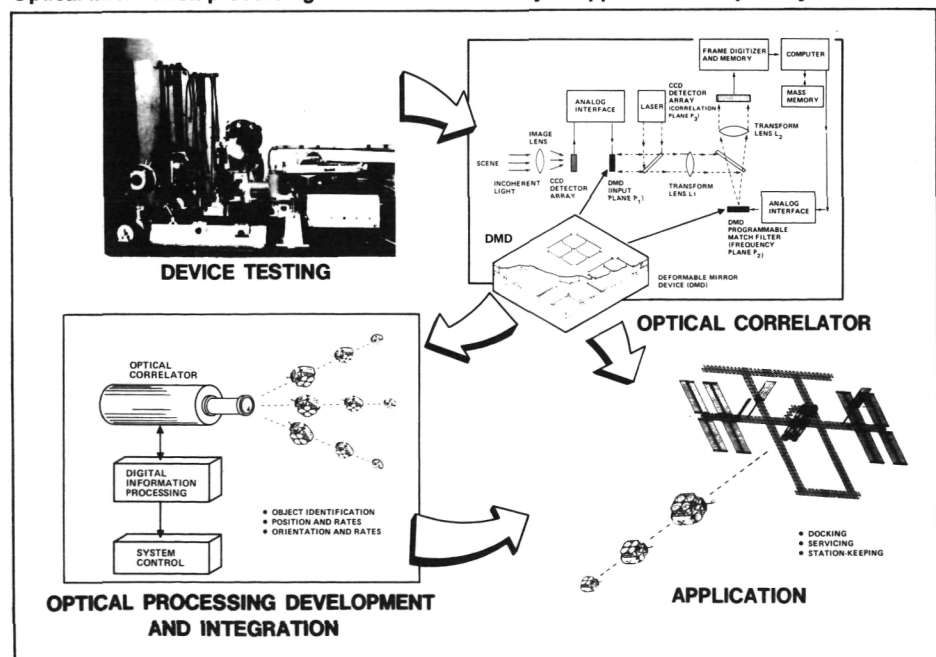
robotic vision. The Johnson Space Center (JSC) has initiated a program to develop a vision system for space applications using the massively parallel capabilities of optical (coherent-light) information processing. Programmable masks are as yet in a rudimentary state and methods of using them in vision systems also need development. The effects of the diffraction pattern of a single element, and methods of compensating for those effects, are one focus of the program. Another focus is the development of devices that have minimal effects requiring compensation. Yet another focus is the implementation of optical processing masks for various vision problems (e.g., discrimination and position estimation).

A hybrid system that mimics nature by distributing the information processing to best advantage between the system's "retina" and the optical correlator will also be constructed. The hybrid system will have a flexibly specified digital spatial mapping from a high-resolution imager to the input modulator in the correlator. Insensitivity to scale and rotation of a viewed object will be the result of one form of mapping, allowing one to use only spatial dither in tracking the object. The elimination

of two dimensions of dither (scale and rotation) greatly increases the speed of the vision system for its use in any sort of control network. Experiments with various mappings will result in the design of VLSI cameras with receptor patterns best suited to drive a subsequent optical correlator.

Major efforts in fiscal year (FY) 1985 were in the development of the Texas Instruments spatial light modulator (SLM) and a correlator including that device as the optically active element. One version of the new SLM configuration was tested. In-house efforts included the design of adaptive methods of using real devices and in the design of the programmable retina. All these efforts will come together in March 1986 with the delivery of the correlator system and its integration with the programmable retina at JSC. Joint research efforts with the U.S. Army are proceeding and are being sought with the Air Force and the National Bureau of Standards. In FY 1985, a presentation of results and plans was made to the NASA Technology Utilization Office and to the armed services, with encouraging response.

Optical information processing will have a wide variety of applications in space systems.



Testing and Analysis of the DOD Ada Language

TM: Stephen A. Gorman/FR12
Terry D. Humphrey/EH4
Reference OAST 9

The Department of Defense (DOD) has chosen Ada as a standard programming language for its future projects to help manage the dramatically increasing costs of software development and maintenance and to improve the adaptability and reliability of deployed target systems. The goal of the Defense Department thrust in Ada is reduction of software life-cycle cost through standardization of language and support software tools across projects and the introduction of sound software engineering principles. Like the DOD, NASA now supports many computer languages and software support environments. It has encountered many of these same problems in its software activities and therefore has a vital interest in utilizing any Defense Department technology which proves effective.

Therefore, NASA and the University of Houston at Clear Lake (UHCL) have established at the Johnson Space Center (JSC) a Beta Test Site for the DOD Ada computer programming language and an associated programming support environment. The approach taken at the Beta Test Site is to combine the academic capabilities of the High Technology Laboratory at UHCL with the more pragmatic approach of JSC personnel and associated contractors to form a team to study Ada and its environment. Currently, more than 20 contractor and government groups are participating in the study. Topics of research range from artificial intelligence to real-time applications to issues of transportability.

The Space Station data management system (DMS) testbed at JSC currently has installed the two DOD-supported Ada systems, the Softech Ada language system (ALS) and the Intermetrics Ada integrated environment (AIE), as well as the Rolm/Data General Ada development environment (ADE) and the Digital Equipment Ada compiler. These systems, along with those at the UHCL, form a solid foundation for Ada-related investigations. In addition to those noted previously, specific areas of research include:

1. A recoding into Ada of real-time code used on the Space Shuttle and written in the HAL/S computer language
2. Development of supporting software tools required for efficient development and maintenance of Ada programs
3. Benchmarking of the four Ada implementations provided in the DMS testbed, including transportability issues

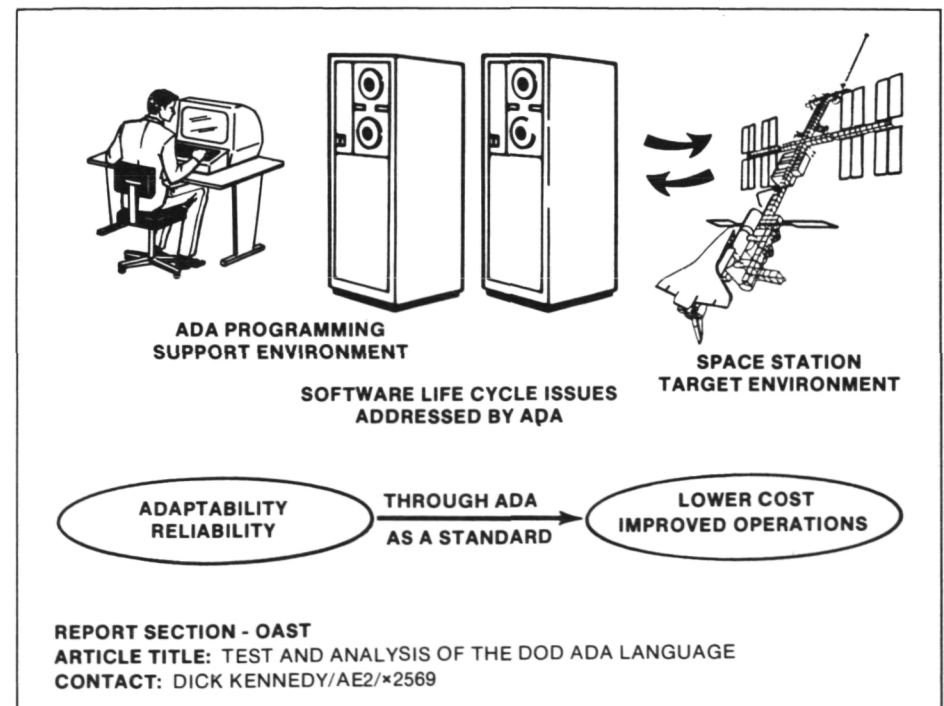
4. Analysis of software testing issues specific to program development in Ada

5. Analysis of issues associated with real-time applications in general

6. Establishing the requirements for run-time environments for target Ada code

The selection of Ada as a standard must be an evolutionary process throughout NASA as different elements move to incorporate the new technology. The Beta Test Site will produce a report outlining the transition issues and suggesting approaches for a straightforward transition.

The JSC's Beta Test Site is investigating issues relevant to the incorporation of the Ada computer language into NASA systems.



STS Guidance and Control

TM: Paul C. Kramer/EH2
Reference OAST 10

On-orbit operational experience in manipulating payloads of various sizes using the Space Shuttle Orbiter indicates a need to better accommodate changes in the combined Orbiter/payload mass-inertia properties and center of gravity location. Present control system technology, as reflected in the Orbiter design, is limited in the range of these properties that can be accommodated without costly and time-consuming software changes. The requirement to ensure adequate stability and efficient performance with vastly different payload mass-inertia properties forces a continuing heavy engineering workload on a mission-by-mission basis. Advanced vehicles such as Space Station will entail much larger changes in configuration characteristics during buildup, with larger uncertainties than ever before.

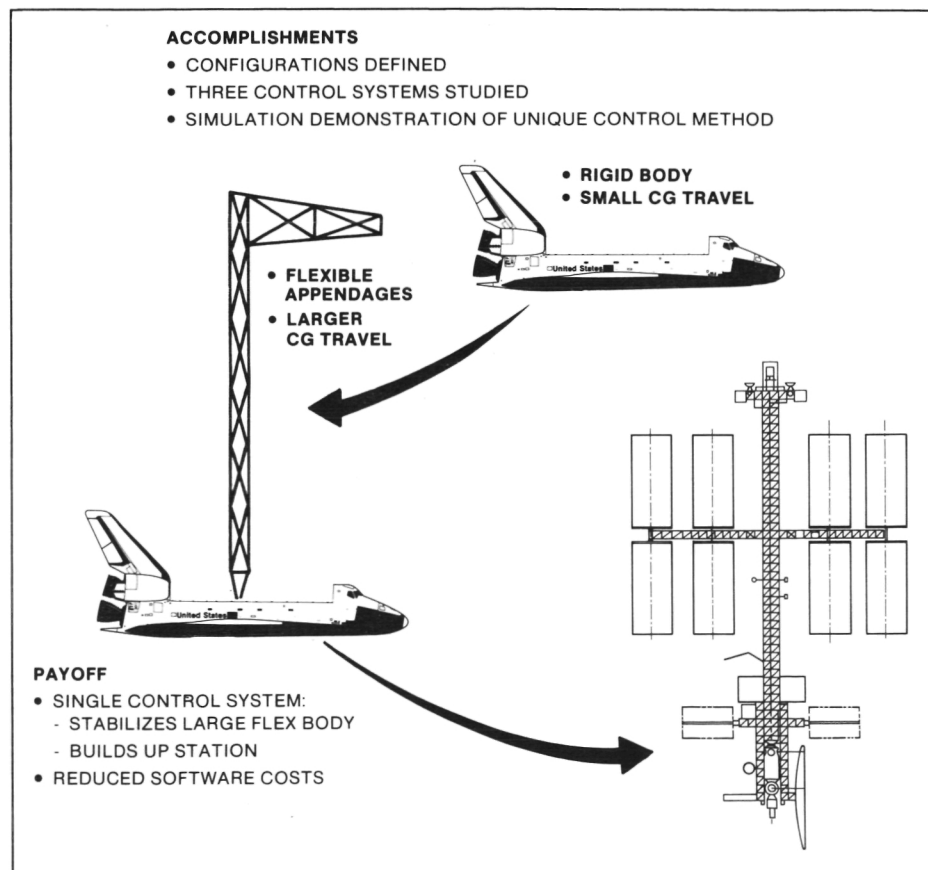
The Johnson Space Center (JSC) is continuing a technology advancement program to create a typical flight control design that is inherently adaptive to large variations and uncertainties in mass-inertia properties, to control effector configuration, and to external disturbances such as aerodynamic and gravity gradient torques.

The program approach is to investigate methods for reducing the potential for dynamic interaction within a digital autopilot, to determine the expected variations and uncertainties of the driving parameters for future vehicles, to develop new methods for providing traceability of design driving requirements through all levels of software and design implementation documentation, and, finally, to apply the resulting design concept improvements to a control system design problem for a typical large, flexible spacecraft. Four specific study areas are required: (1) definition of the limit of the present control envelope, (2) development of a new method for software requirements documentation and control, (3) definition of the scope of the requirement for adaptive control through long-range planning studies, and (4) development of requirements and software models for a large-vehicle control system that is autonomously adaptive to all rigid-body and external disturbance parameters.

A major milestone in the program was reached when a new and unique method for on-orbit attitude control, termed the optimal rotation algorithm (ORA), was developed and demonstrated in simulation studies using the STS Orbiter reaction control system. The ORA controller incorporates a new, fast, and powerful algorithm for the solution of fuel-optimal, fixed-endtime attitude maneuvers using linearized spacecraft dynamics and coupled on-off control. Advantages of the advanced design concept are (1) savings of about one-fourth of the propellant required in velocity rotational maneuvers, (2) reduction of one-half of the jet duty cycles, resulting in significantly extended jet life, and (3) desensitizing the dynamic interaction between the Orbiter control system and heavy flexible payloads.

The ORA design was delivered to the Orbiter program and is being considered as a candidate for programmatic development and flight testing of an upgraded digital autopilot.

Advanced control technology will provide highly adaptive and powerful systems.



Advanced Autopilot for Spacecraft

TM: Edward T. Kubiak/EH2
Reference OAST 11

The design of the Space Shuttle on-orbit digital autopilot was constrained by the important design goals of minimum computer core size and required central processing unit (CPU). These goals were met but with some sacrifice in performance and failure tolerance characteristics. Subsequently and independently, a technology effort was initiated to design a new autopilot concept to maximize performance and failure tolerance, without hard constraints on core or CPU. Conceptually, this new design was to be generic in nature and applicable to any spacecraft.

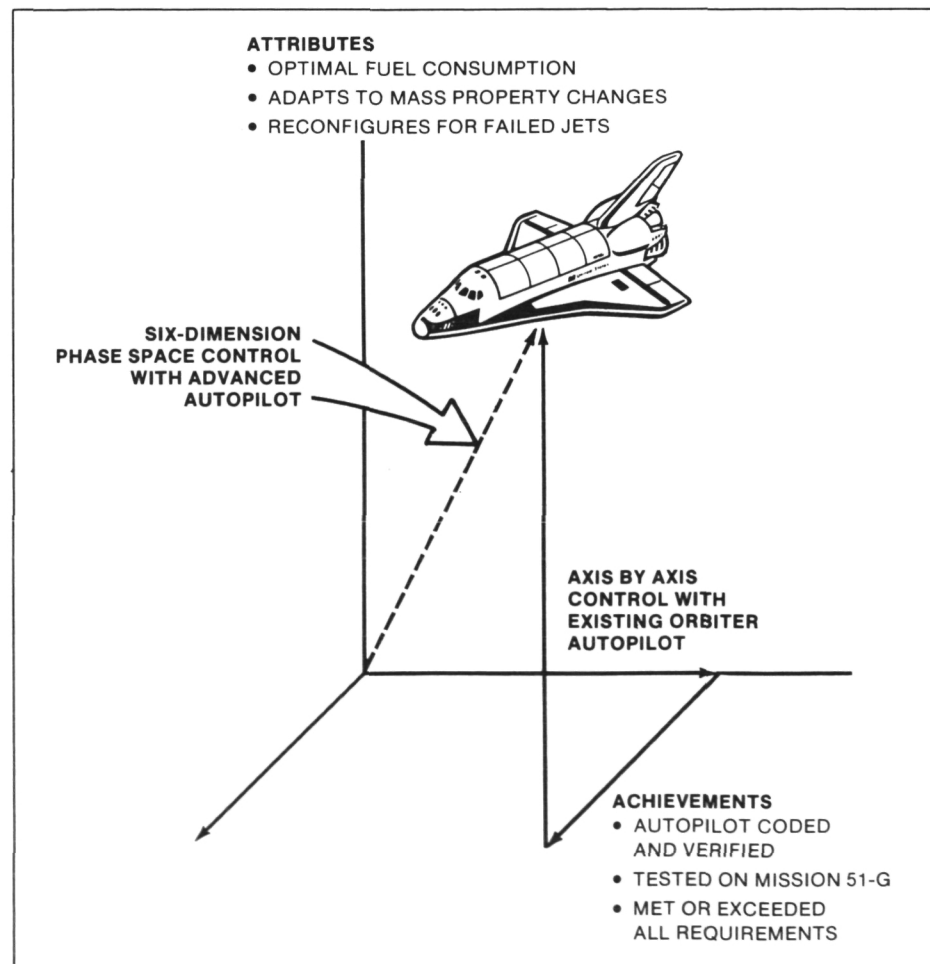
This new design, advanced autopilot for spacecraft (AAPS), was implemented for the Orbiter reaction control system (RCS) thrusters. It differs from traditional designs in two major respects. First, its switching logic is not performed on a per-axis basis and does not output a simple on-off command to the jet selection logic for the RCS thrusters. Instead, it uses a phase space switching scheme which operates in all six dimensions (rotation and translation) and outputs a six-component vector of commanded rate changes. Second, its jet selection logic is not cyclic but uses linear programming techniques to optimize a sequence of thruster firings that will produce the required rate changes with minimal RCS propellant usage. These major differences not only improve performance and failure accommodation but also facilitate the incorporation of new capabilities such as special control modes and automatic stationkeeping.

The AAPS was coded in the Orbiter software for STS missions 51-G and 61-B along with the current digital autopilot (DAP) such that the crew could easily select or reselect either flight control design. The STS 51-G flight test occurred in June 1985 and was highly successful, meeting or exceeding all anticipated requirements. New control modes tested included an acceleration command mode which substantially reduces the usual coupling between axes, a translational position pulse mode not available in the current design, and another new mode which allows mixed operation of the primary and vernier RCS. The last mode is particularly valuable because it can reduce the normally high vernier usage rate and allows primary backup (replacement) of a failed vernier, a failure which otherwise might completely abort vernier usage. The final successful test element demonstrated the capability of closed-loop stationkeeping with a phantom target, since no suitable target was available on this mission.

Propellant usage for the entire set of test procedures was lower than anticipated, and the results indicated that reductions of 20% or more are achievable with the new design.

This AAPS technology demonstration has sparked a development effort to include permanently some of the AAPS features in the Orbiter software to improve performance and provide the capabilities required to support advanced missions.

Features of advanced digital autopilot.



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Orbiter Experiments Autonomous Supporting Instrumentation System

TM: Earl W. Tiedt/EX3
Reference OAST 12

In previous years, the Orbiter Experiments (OEX) Program sponsored the development of an experiment designed to obtain in-flight measurements of the Space Shuttle Orbiter payload bay environment. The experiment was developed by personnel of the NASA Goddard Space Flight Center (GSFC) and flown on several early flights. A dynamic, acoustic, and thermal environments working group, chaired by the GSFC, is continuing these investigations. Current interest is in the area of launch environment effects on payloads.

For efficient data acquisition, a new flight data system was needed with sufficient autonomy to be installed in the Orbiter late in the launch processing flow if required. In addition, a highly mobile ground instrumentation system was needed to provide data reduction in support of factory and launch site integrated tests.

With funding support from the U.S. Air Force, NASA has developed a flight data system and ground support instrumentation which meets these requirements. The development of the Orbiter

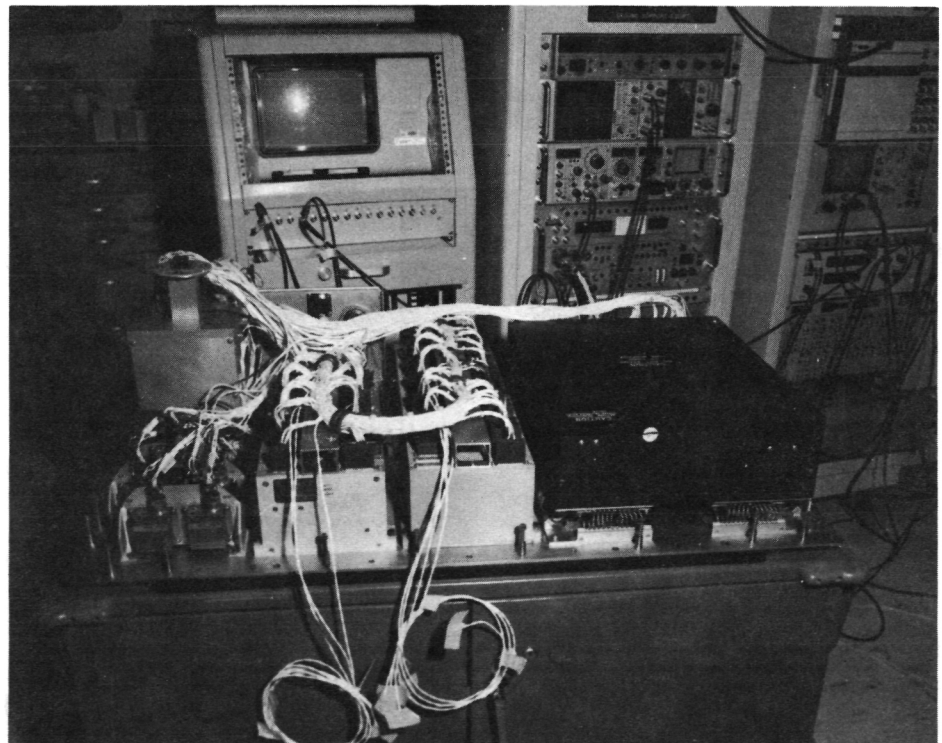
experiments autonomous supporting instrumentation system (OASIS) was accomplished in the JSC Flight Projects Engineering Instrumentation Laboratory.

The flight system provides Orbiter power and control interfaces, signal conditioning, data processing, and storage for the payload-mounted transducers. The system consists of a control module which interfaces with the Orbiter payload services for commanding, power, time, downlink, housekeeping, and ground checkout. The control module decodes the uplinked commands and sets the OASIS electronics to the desired operating status. Signal conditioning is provided for 64 wideband and 97 low-frequency measurements. Six wideband units and one static pulse code modulation unit provide 2.414 megabits/sec of data to a 28-track modular airborne recording system magnetic tape recorder.

The ground instrumentation system that was developed can fully exercise and monitor the OASIS and has the mobility for remote site use. It provides simulated Orbiter command and monitoring interfaces, data decommutation and presentation capability, ground recording for data dumps, and generation of flight data tape duplicates. The system has supported test and checkout efforts at the Inertial Upper Stage/Airborne Support Equipment facility in Kent, Washington, and at the Orbiter Processing Facility and the launch pad at the NASA Kennedy Space Center. It is scheduled to support test and checkout at the Vandenberg Launch Site in the near future.

The flight performance of the system has resulted in the project receiving a Performance Excellence Award from the U.S. Air Force Space Division. Shown in the illustration is the flight system installed on its transporter with associated ground support equipment.

The OASIS system mounted on a transporter with associated ground support equipment.



Space Sciences and Applications Life Sciences

Summary

Office of Space Sciences and Applications

Life Sciences

Summary

Eight Space Shuttle flights were completed in fiscal year 1985, twice the number of flights in any previous year. The effort to improve and simplify medical operations on the Space Shuttle is being realized. In addition, conceptual plans for the medical aspects of a Space Station are maturing and now include both in-house and extramural efforts. In-house conceptual studies of Life Sciences aspects of a manned Mars mission have begun. The Johnson Space Center (JSC) continues to conduct a broad range of medical research projects in support of the following Life Sciences Program goals:

1. To ensure the long-term health, well-being, and performance of humans in space, to characterize the medical constraints of space flight, and to facilitate participation by a broad segment of the population

2. To use the space environment as a means of increasing fundamental knowledge in medicine and biology

3. To conduct the research and technology development necessary for maintaining life in space on a self-sustaining basis for long periods.

The Medical Sciences Space Station Working Group, which was first organized in June 1982 and which did much of the early planning in medical sciences for the Space Station, changed focus and emphasis and was reorganized and renamed the Medical Sciences Lunar and Planetary Planning Group (MSLPPG) in April 1985. The group contributed to the writing of the Life Sciences section of the 70-page Manned Mars Mission Document prepared by NASA and Los Alamos National Laboratory personnel primarily for the President's National Commission on Space. In addition, individual members

wrote the following 8 of the 80 backup papers: EVA and Suit Technology, Radiation Environment and Radiation Biology, Considerations for Crew Size and Composition, Health Maintenance, Human Adaptation and Readaptation, Soviet Medical Observations: Long-Duration Missions, Psychological Issues, and Toxicological Control in the Mars Station.

In order to bring outside ideas into the working groups and to others at JSC, the MSLPPG sponsored the following seminars: Miscellaneous Notions on Life Sciences Aspects of Manned Mars Exploration, Implication of Antarctica Experience for a Manned Mars Mission, Plant Research Needed for Mars Missions, Low Pressure Effects on Agricultural Plants, Organic Contaminants of Submarine Air-Predictor for Extended Patrols, Life in Harsh Environments, Mars Overview, Exercise Prescriptions for Long-Duration Space Flights: How Much? How Long? How Often?, Life Support in Mars, and "Jello" Bubbles and the Bends — Prevention of Gas Bubbles in the Space Environment.

As a result of the planning group efforts to date, the following three areas of research were identified as the key areas which need to be studied in preparation for long-duration flights such as a manned Mars mission: artificial gravity (AG) effects, radiation effects and protection from radiation, and adaptation to long-duration missions. In-house efforts have helped to identify postflight physiological changes in humans. Some of the important changes which occur are the following:

1. Otolith organs send out uncharacteristic signals to which the nervous system must adapt.

2. Proprioceptive input greatly diminishes.

3. Muscles of locomotion and posture begin to atrophy.

4. Portions of the skeleton needed for ambulation and standing lose bone mineral.

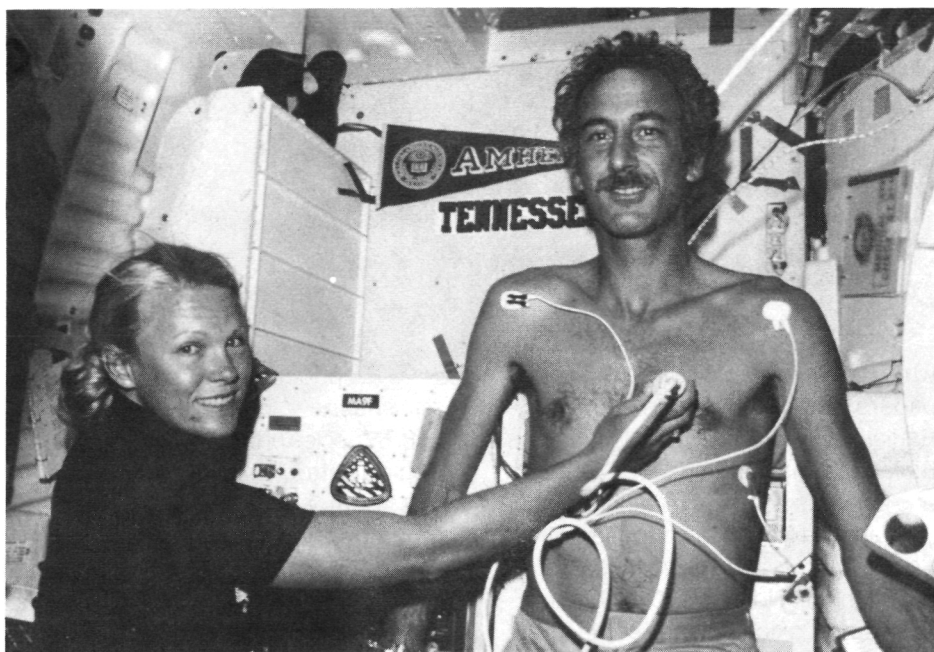
5. The increased availability of bone and muscle constituents requires renal, gastrointestinal, and hematological adjustments.

6. Labile portions of the extracellular fluid are excreted as they are no longer needed.

7. Fluid adjustments tend to unload the heart and, thereby, to decrease its end diastolic volume and to cause cardiac muscle changes.

1985 Physiological and Life Sciences Related Investigations

During the last year, developing an understanding of the physiology of space motion sickness (SMS) has been given an increased emphasis. The recently established NASA Space Biomedical Research Institute (SBRI), supported by the Universities Space Research Association (USRA) Division of Space Biomedicine, has added Dr. Parker as resident investigator. Postflight change in motion perception is one area of study. If SMS is a consequence of adaptation to the sensory rearrangement associated with microgravity, preflight training might preadapt astronauts to SMS. Results from several experiments during the year support the hypothesis that after the brain adapts to prolonged microgravity, otolith signals elicited by head tilts during entry or on Earth immediately postflight are interpreted by the brain as indicating linear movement. Also during the year,



Astronaut Rhea Seddon, M.D., performing echocardiogram measurements on fellow Mission Specialist Jeffrey Hoffman during the 7-day STS 51-D Space Shuttle flight.

experiments using a rotating chair have been designed for use in Space-lab. Targeted for implementation on the first international microgravity laboratory flight in May 1987, these experiments will study the effect of a sudden drop on the "H" reflex.

Researchers at NASA-JSC have used echocardiography to study crewmembers' hearts before, during, and after Shuttle flights, as illustrated. The preliminary in-flight data suggest that the major cardiovascular adjustments take place within approximately the first day in flight. By the second day, the heart is smaller than it was preflight. Postflight data indicate that the return of the left heart volume to preflight values follows an oscillatory time course over the first week after the mission, and that possible decreases in heart mass might accompany this change without a reduction in overall heart performance. From these initial results, investigators concluded that the cardiovascular system responds and changes because of the shifting of body fluids and loss of blood volume during space flights. However, the return to baseline values after short flights and the long-term adaptation of

the cardiovascular system may be relatively slow.

The examination of the mechanisms involved in physiological changes demonstrated in bone, muscle, and blood after exposures of humans and animals to microgravity is continuing. Nuclear magnetic resonance (NMR) devices will be used to design effective countermeasures.

The change of pressure from the Space Shuttle cabin (14.7 psi) to that of the extravehicular activity (EVA) suit is great enough to cause symptoms of altitude decompression sickness. Tests conducted at JSC in the last 3 yr to verify altitude decompression protocols have shown that symptoms and detectable venous bubbles after 3.5- and 4.0-hr oxygen prebreathe periods occur more frequently than has been anticipated previously during EVA. The long (6 hr) duration of the exposure and the continuous low level of exercise could cause this increase.

The use of exercise as a preventive countermeasure on Space Station has potential for reducing or eliminating some of the deleterious effects of long-term microgravity exposure. Limited in-flight experiences indicate that

in-flight degradations of aerobic capacity and muscular strength are reduced if crewmembers accomplish appropriate exercise while in flight. The operational reasons for developing these physiological countermeasures are primarily to facilitate readaptation to one g and to maintain conditioning for vigorous EVA and for emergency egress situations. A treadmill, a bicycle ergometer, and an anaerobic upper body strength device are currently recommended as the major exercise modalities (see illustration). Two related techniques for reducing the deconditioning associated with space flight are lower body negative pressure and electrical muscle stimulation. Both of these techniques, although experimental at this time, have potential as deconditioning countermeasures.

Preparation of a health care delivery system for Space Station has begun. An active preventive medical program will be made available to minimize the need for early mission termination because of medical problems. The health maintenance facility (HMF), now under development, should be modular and flexible to allow future growth and equipment replacement for state-of-the-art advances.

A complementary development for in-space health care is an in-flight intravenous injection system to replace lost body fluid. Such a system will be mandatory for long-duration space missions.

The JSC Toxicology Laboratory has the overall responsibility for ensuring that the Orbiter's crew environment is toxicologically safe. During the report period, the analyses of cabin atmospheric samples and a number of spacecraft hardware off-gassing lists were performed. A solid sorbent air sampler, which samples atmospheric contaminants continuously over an entire mission, was flown and found to be a highly sensitive detection device. A developmental program was initiated for an onboard atmospheric analyzer for the Space Station utilizing the illustrated ion trap detection system.

A carbon formation reactor has been investigated as a means of air



Conceptual exercise preventive countermeasure system.

revitalization in manned spacecraft on long-duration missions. Small-scale design support test results demonstrated the feasibility of a carbon formation reactor developed and tested during 1985.

Man-modeling and data collection have been used as tools to ensure that the human element is incorporated into spacecraft design beginning with the preliminary design stage. Accomplishing this goal realistically requires models and data describing how the human interacts with his or her environment. This incorporated information can be made available to the designer through computer-aided design and computer-aided engineering work stations.

Also, interactive computer graphics for man/machine evaluations and man/machine engineering have been under development for several years. The two interactive computer graphics programs, PLAID and TEMPUS, are among the tools used to enhance crew productivity by evaluating equipment, vehicle, and operations designs. The PLAID software package models detailed work environments; the complementary TEMPUS program generates realistic man-models to be in-

corporated into PLAID environments.

Many experiments are being developed in preparation for Spacelab flights over the next several years. The JSC is directly responsible for developing and implementing some of the experiments and for providing flight-qualified hardware for others.

Payload management and implementation extends over the life of the experiments and includes support for timeline development, testing and integration of hardware, flight simulations, crew training, flight support software, in-flight operations, and launch and landing site operations (see illustration).

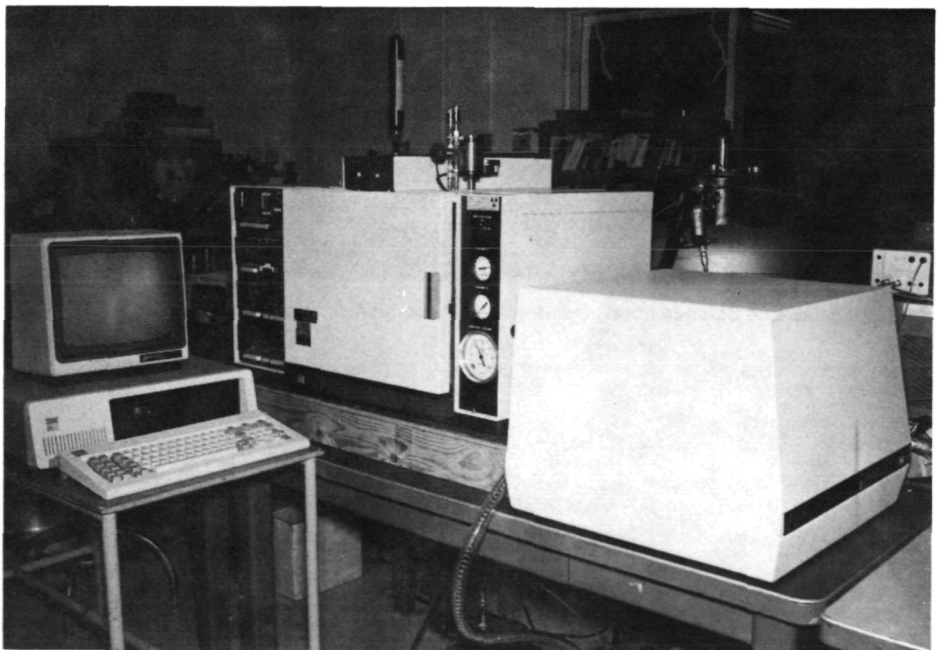
The Life Sciences research on humans is in several disciplines including cardiovascular/cardiopulmonary, vestibular, metabolic, and behavioral/human factors. Approximately 20 such experiments are currently manifested and being actively supported.

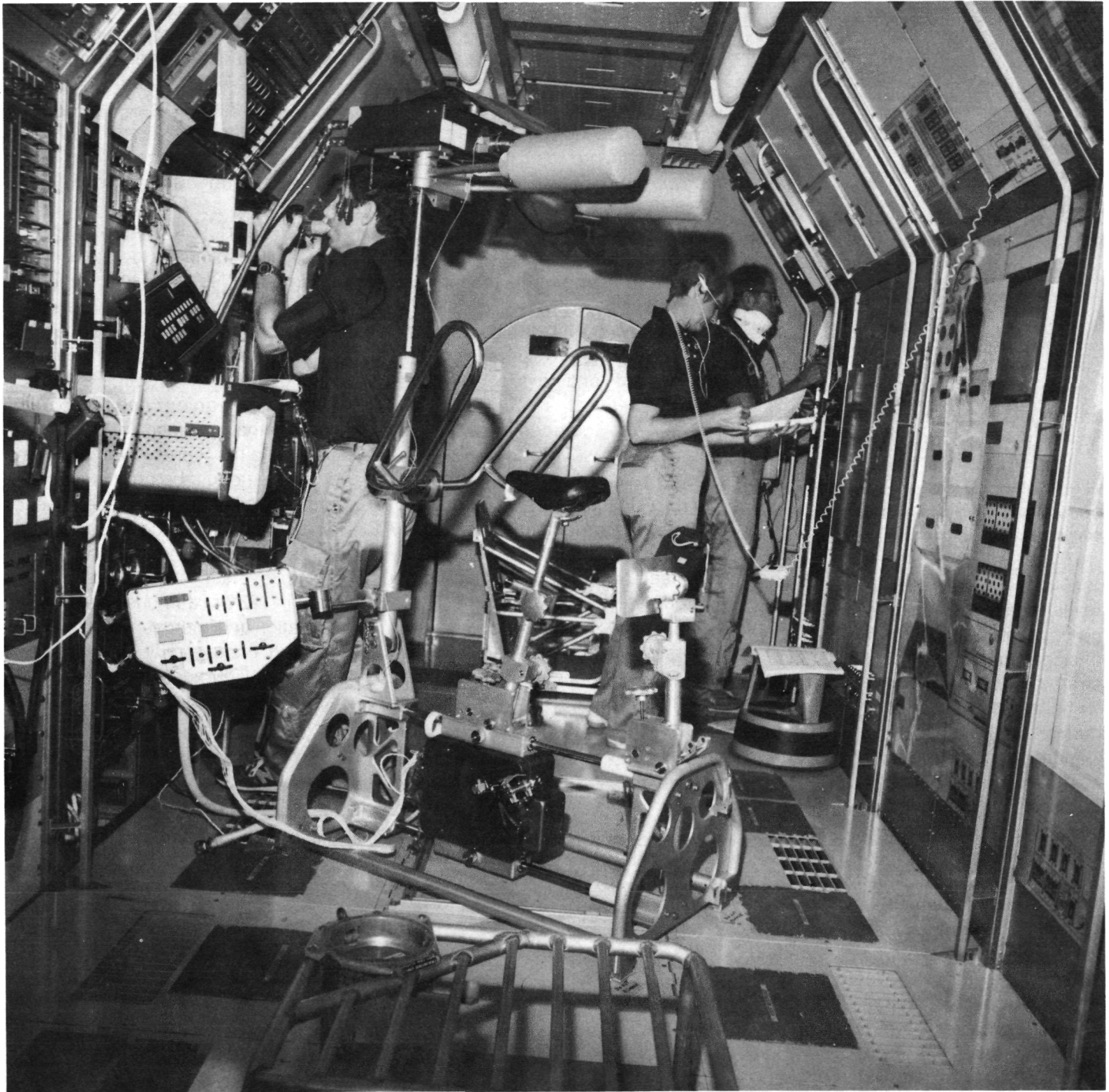
A prime NASA goal is to demonstrate a means of using the space environment to the benefit of man on Earth; toward that end, such products as

biological compounds with pharmaceutical value are being examined. The continuous-flow electrophoresis system (CFES) is being used to separate heterogeneous mixtures of human embryonic kidney cells into homogeneous fractions, some of which are useful in combating human-produced disease.

The effort to develop a space bioreactor continues a long-term NASA commitment to biological research and development in space. The space bioreactor currently being developed is designed to sustain a mammalian cell culture. It will produce a solution of urokinase, an enzyme that participates in the dissolution of blood clots. This protein is representative of many drugs that could be produced by the same process. A small space bioreactor for the Orbiter middeck, consisting of a small culture vessel and related control system, is now scheduled for flight in 1987 to demonstrate systems operation and improvements or limitations in microgravity and to obtain baseline flight data for future full-scale flight experiments.

Laboratory ion trap detector system with (left to right) the IBM PC-XT data system, a gas chromatograph, and the ion trap detector.





The Spacelab Life Sciences crew training in a Spacelab mockup.

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Space Sciences and Applications Life Sciences

Significant Tasks

Space Motion Sickness Preflight Adaptation Training

TM: John W. Harris/SB
PI: Donald E. Parker/SB
Reference OSSA 1

Space motion sickness (SMS) has been reported by about one-half of the Space Shuttle astronauts. Preflight training frequently has been proposed as a potential solution to the problem of SMS. If SMS is a consequence of adaptation to the sensory rearrangement associated with weightlessness and if preflight training can preadapt astronauts to that sensory rearrangement, the training could afford astronauts significant relief from SMS symptoms.

Several investigators have noted that weightlessness rearranges the relationships among signals from visual, skin, joint, and vestibular receptors. Prolonged exposure to weightlessness results in adaptation, as indicated by reduced subjective disturbance during voluntary movement after the first days of orbital flight, as well as perceptual and physiological reflex changes during Space Shuttle entry and immediately after flight. This determination suggests that SMS is a side effect of the adaptation process.

Results from several experiments support the hypothesis that after the brain adapts to prolonged weightlessness, otolith signals elicited by head tilts during entry or on Earth immediately after flight are interpreted by the brain as indicating translation. Based on this otolith tilt-translation reinterpretation hypothesis, a concept for preflight adaptation training (PAT) apparatus and procedures has been proposed. In the PAT trainer, relationships between otolith responses associated with the subject's movements and the visual scene presented to him are systematically altered. Normally, when the subject's head is rolled toward his left shoulder, the visual scene rotates around the corneal-retinal axis in the direction opposite to the head tilt. In the trainer, a leftward head roll results in translation of the visual scene toward

the left without rotation; i.e., the vertical axis of the scene remains aligned with the vertical retinal meridian. Normally, when the subject's head is pitched backward, the visual scene moves downward in the visual field. In the trainer, backward pitch is associated with apparent flow of the visual scene toward the subject, but the horizontal axis of the scene remains aligned with the horizontal retinal meridian.

Prolonged exposure to the sensory rearrangement produced by the PAT trainer should result in neural recalibration of relationships between otolith and visual neural signals. It is hypothesized that PAT will result in self-motion perception reports and eye movement reflexes that are similar to those observed immediately after flight in weightlessness-adapted astronauts.

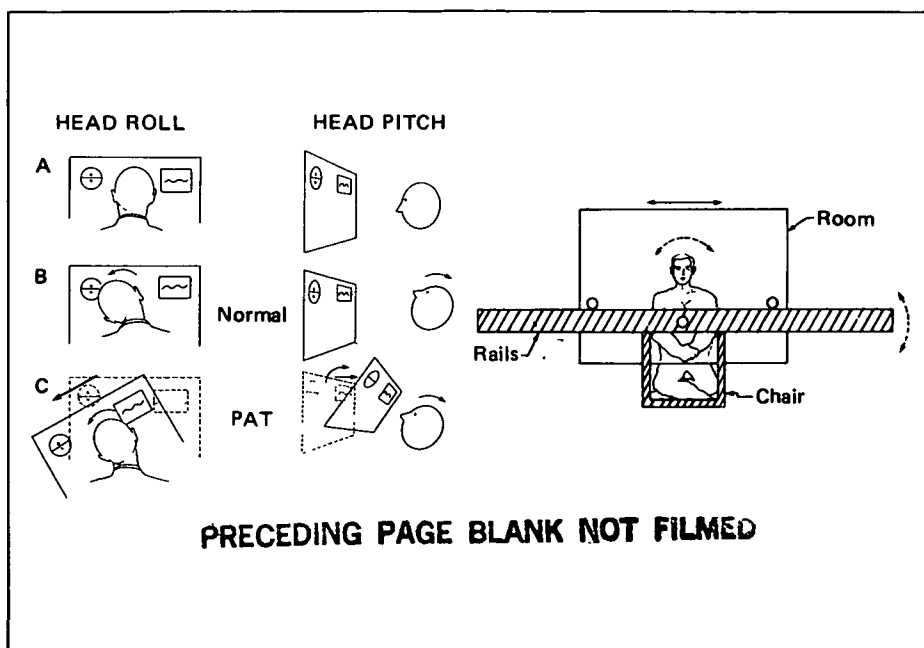
Three PAT prototype trainers have been developed. The Miami University seesaw (MUS) and one utilizing the Wright-Patterson Air Force Base dynamic environment simulator (DES) include a physical room that is moved relative to the restrained subject. The subject is moved passively in the MUS and DES prototypes. The third prototype trainer employs a computer-generated scene and presents the image of a room to the subject. Apparent movement of the room is produced by the

subject's voluntary head movements. This third trainer uses the Wright-Patterson Air Force Base visually coupled airborne systems simulator (VCASS).

Several preliminary experiments have been completed. The results indicate that eye movement reflexes can be changed by the trainer sensory rearrangement. Tactile motion cues appear to potentiate the effects, which persist for at least several minutes after training. Manipulation of phase relationships between the roll stimulus presented to the subject and room translation appears to alter eye movements in some subjects; however, the nature of these changes varies across subjects. The VCASS results were dissimilar to those obtained with the MUS and DES trainers. The discrepancies may be attributable to several factors, including differences between simulated and physical rooms as well as differences between voluntary and involuntary head motion during training.

Although numerous problems need to be addressed, it does appear possible that apparatus and procedures can be developed to preadapt astronauts to the sensory rearrangement of weightless space flight.

Concepts for preflight adaptation training devices.



Altitude Decompression Sickness Studies

TM: James M. Waligora/SD3

PI: David J. Horrigan/SD3

Reference OSSA 2

The change in pressure from the Space Shuttle cabin (14.7 psi) to that of the extravehicular activity (EVA) suit is great enough to cause symptoms of altitude decompression sickness. Tests conducted at the Johnson Space Center in the last 3 yr to verify altitude decompression protocols have shown that symptoms and detectable venous nitrogen bubbles after the 3.5- and 4.0-hr oxygen prebreathe periods are more prevalent than had been anticipated during altitude-chamber-simulated EVA. This increase is believed to be brought about by the long duration of the exposure (6 hr) combined with the continuous low level of exercise. These data indicate that extrapolation from shorter duration aircrew activity simulations (previously baselined) cannot be reliably employed.

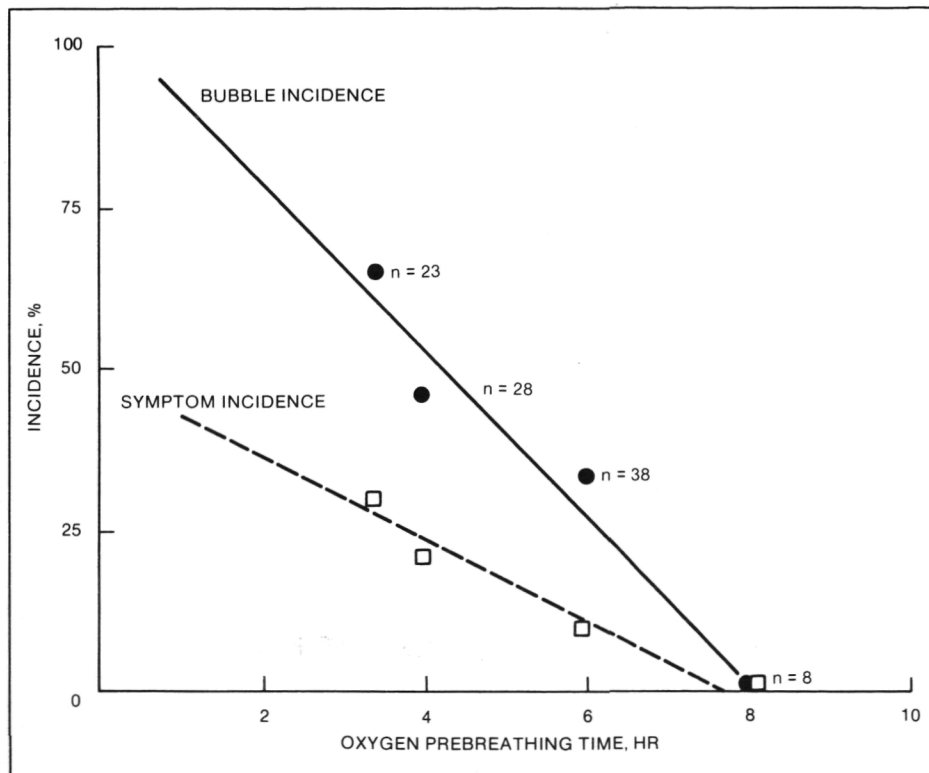
A study was undertaken to collect data on symptom and venous bubble incidence during simulated EVA after prebreathe periods of 6.0 and 8.0 hr to combine with the existing data on incidence of symptoms and bubbles with oxygen prebreathe time for EVA. The test involved (1) an exposure of 38 subjects to a 6-hr oxygen prebreathe period followed by decompression from 14.7 psi to 4.3 psi and (2) an exposure of 8 subjects to an 8-hr prebreathe period followed by decompression from 14.7 to 4.3 psi. Wearing oxygen masks, the subjects worked at EVA-representative tasks for a 6-hr period. At 16-min intervals during this period, a Doppler bubble detector was used to detect venous gas bubbles. At the end of the 6-hr exercise period, the subjects were returned to ambient pressure.

Results of the studies indicate approximately a 50% reduction in incidence of symptoms and detectable venous bubbles when the prebreathe time is extended to 6 hr. The 8-hr prebreathe protocol resulted in a complete reduction to no detectable instances of symptoms or bubbles. This work has provided a useful additional insight into the understanding of altitude decompression sickness prevention and will aid in the selection of cabin and suit pressures for the Space Station.

Subject involved in a work task during altitude decompression tests.



The incidence of venous gas bubbles and symptoms of sickness during exposure to 4.3-psia pressure after oxygen prebreathe.



Preparing a Health Care Delivery System for the Space Station

TM: James S. Logan/SD
Reference OSSA 3

Space Station represents the start of man's permanent presence in space. It will be a manned facility orbiting the Earth with a crew of six to eight astronauts, and mission duration for each crew is expected to be about 90 days. Illnesses and accidents will inevitably occur in this new environment. An absolute requirement is the development of an in-flight health care delivery system that will minimize potential risks, accurately diagnose acute medical/surgical conditions, and successfully treat as many conditions as possible. A well-planned in-flight health care delivery system will help achieve NASA's goals of maintaining the health and safety of the crew, preventing unnecessary rescues, and making necessary rescues successfully.

Many factors impact the requirements for an in-flight health care delivery system. Mission duration must be considered, and no immediate return or rescue capability will exist. An unscheduled rescue is expected to cost as much as \$200 million and require 14 to 28 days of preparation before launch. Frequent extravehicular activities (EVA's), many of which will involve potentially dangerous heavy construction and berthing activities, will pose a risk of injury. Frequent handling of potentially toxic substances derived from materials processing, manufacturing, and long-term cohabitation in a closed environment will also increase this risk. Also worrisome is the decrease in cardiovascular fitness, muscular strength, and immune response observed in the micro-g environment.

Providing enough personnel and equipment to diagnose and treat adequately every conceivable illness that may occur aboard Space Station will be impossible. For example, a ruptured aorta would probably be a nonsurvivable injury aboard Space Station. Planning is focused on events that have a

relatively high probability of occurrence and pose a significant threat to the crew. A thorough health hazards analysis of types of activity and toxic materials aboard Space Station is being conducted to quantify risks. Medical problems encountered on previous flights have included such events as cardiac arrhythmias and chemical pneumonitis. The physiological changes occurring in micro-g must be considered; the combination of micro-g-induced hypovolemia and calcinuria probably increases the risk of kidney stone formation.

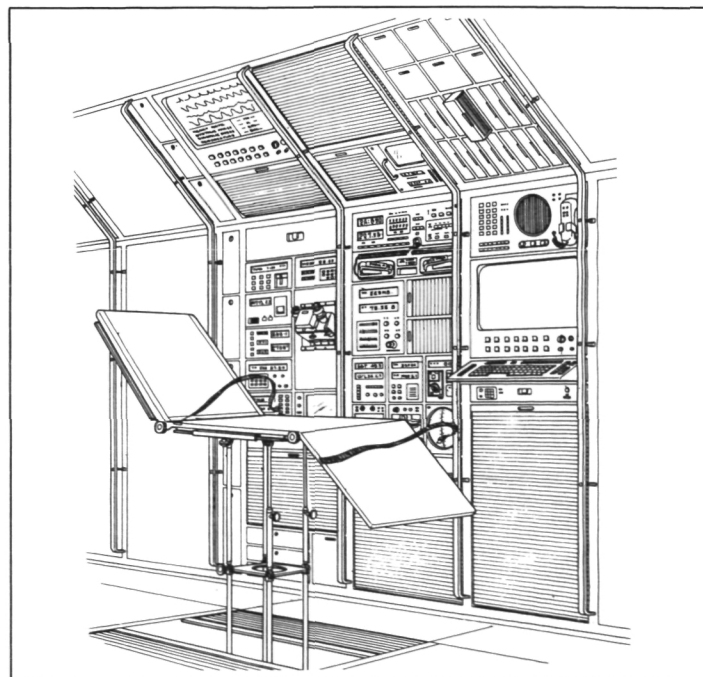
The primary goal of Medical Operations aboard Space Station is to ensure the health and safety of the crew. An active preventive medicine program will be utilized to minimize early mission termination because of medical contingencies. Medical expertise and diagnostic and therapeutic equipment must be available in flight to differentiate life-threatening problems from self-limiting minor illnesses, to prevent unnecessary rescues, and to sustain the patient should a rescue be required.

Currently, weight and volume constraints for the health maintenance facility (HMF) are approximately 1200

lb and 65 ft³. To meet these constraints, NASA will have to make use of advances in medical technology miniaturization techniques and medical equipment automation. Equipment must be simple and reliable, meet standard Space Station interfaces for power, thermal, and data subsystems, and be micro-g compatible. The HMF should be modular and flexible to allow future growth and equipment replacement for state-of-the-art advances. The capabilities of the HMF may vary from mission to mission, where unique activities pose unique threats to crew health.

A preliminary HMF design that meets NASA's weight and volume constraints has been developed. The HMF is located in one of the habitability modules. Most of the diagnostic and therapeutic equipment is housed in three standard 19-in-wide racks, and exercise equipment is provided in two large stowage compartments in the subflooring. A portable patient restraint is stored on the side of the end rack. Expansion to a four-rack design could greatly augment life support, digital imaging capabilities, and toxicological analyses. However, any decision to expand the HMF must be justified on the basis of genuine medical requirements.

Current concept for a health maintenance facility with the patient restraint device deployed.



In-Flight Infusion System

TM: Richard L. Sauer/SD

PI: Jerry Colombo/SD

Reference OSSA 4

Medical emergencies, especially those resulting from accidents, frequently require the administration of intravenous fluids to replace lost body liquid. A system to provide this capability in space was recognized as an essential component of the permanently manned Space Station. Storage and weight limitations on space vehicles preclude the inclusion of large quantities and varieties of injectable or infusible materials. The handling and transfer of fluids under conditions of microgravity during space flight further impacted the design of an intravenous injection system.

A system has been developed which provides for the infusion of fluids that have been prepared from concentrates using specially treated in-flight water. This system is simple, reliable, and easily used, and it should have an extended shelf life. The weight and volume of the injection system has been reduced significantly by providing the injectables in concentrated form. They are then reconstituted through the addition of water from the spacecraft

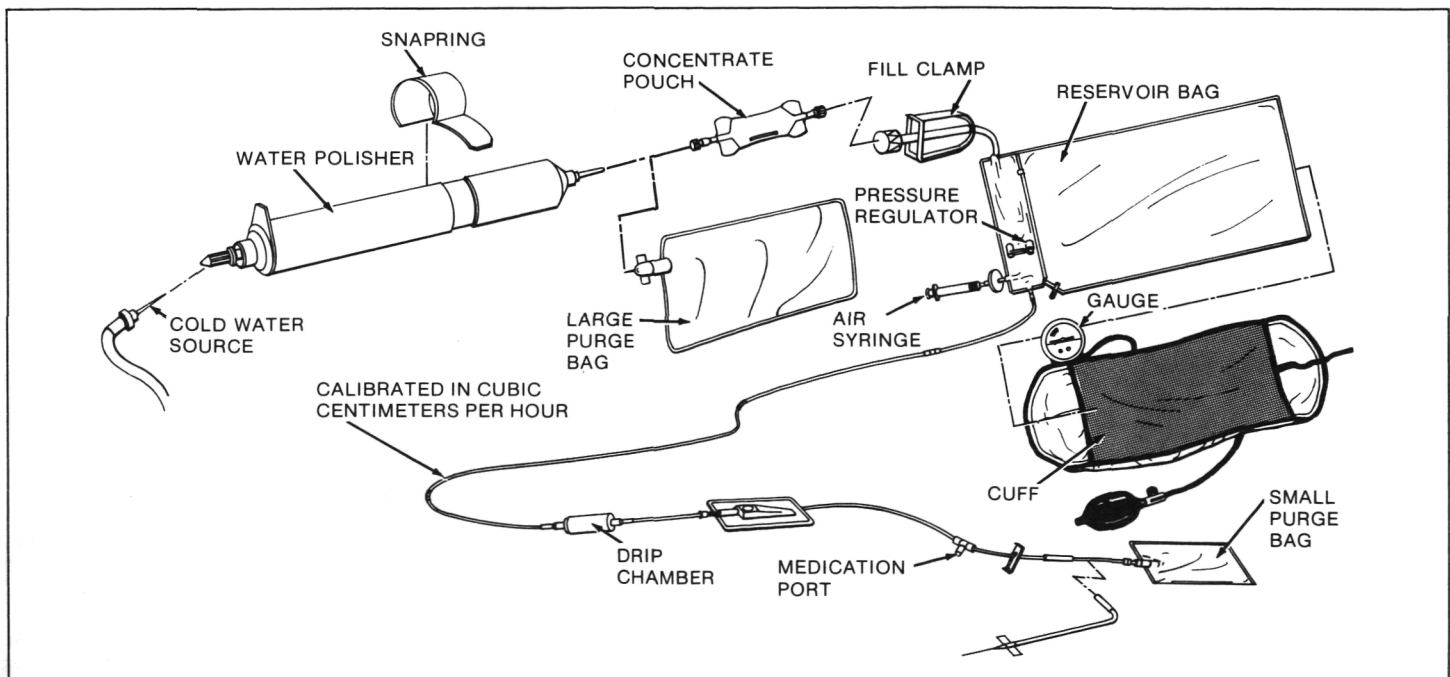
potable water system prior to being administered. This water, however, requires special treatment in order to meet injectable requirements.

The device developed to produce this water assures that the three types of possible contaminants (microbiological, inorganic chemicals, and organic chemicals) are removed to levels meeting the U.S. Pharmacopeia (USP) injectable fluid requirements. Microbiological contamination control is provided by iodination; inorganic materials are removed by cation and anion exchange resins; and organic materials are controlled by activated charcoal. Potable water from the spacecraft system is introduced into the device via a hose fitted with a needle. The needle punctures the first membrane of a sealed bactericide cartridge containing iodinated resin. This resin produces 2 p/m (mg/liter) of elemental iodine and is maintained in a sealed cartridge to prevent the migration of the iodine from the resin into the remainder of the purifier during storage. A second membrane downstream of the iodinated resin is punctured by pushing the two sections together. The water thus passes through the cation exchange resin and the anion exchange resin, where the inorganic and selected

organic chemicals are removed. Subsequently, an activated charcoal bed removes any remaining organic compounds which may be in the feedwater in addition to materials which may bleed from the ion exchange resins. Finally, the water passes through a particulate filter. The product water has been tested and shown to meet the USP injectable fluid requirements routinely.

This product water is routed such that it then flushes the concentrate into the infusion bag, where it is mixed and then pressurized using an inflatable cuff. Flow rate or infusion rate is controlled by an adjustable pressure regulator. Flow measurement is provided by introducing a small bubble of air into a section of calibrated tubing. From measurements of the bubble's progress through the tubing during a specified time, a quantitative measurement of the flow/infusion rate is provided. The bubble and any other free gases that might be present are removed just prior to infusion by a combination hydrophobic/hydrophilic water/gas separator. In addition, a microgravity drip chamber provides a visual indication and verification that flow is occurring.

In-flight infusion system.



Solid Sorbent Air Sampler

TM: Duane L. Pierson/SD4

PI: Theodore J. Galen/SD

Reference OSSA 5

Monitoring of the Space Shuttle cabin atmosphere is a major responsibility of the Toxicology Laboratory at the Johnson Space Center. This toxicological monitoring focuses on the breathing atmosphere. The presence of trace amounts (magnitude p/m or less) of volatile compounds in a closed environmental control and life support system can expose the flightcrew to such compounds. The toxicity of some volatile contaminants may adversely affect specific physiological parameters and the efficiency of the crew. Therefore, preflight and in-flight monitoring of the spacecraft atmosphere is essential to determining the levels of these contaminants.

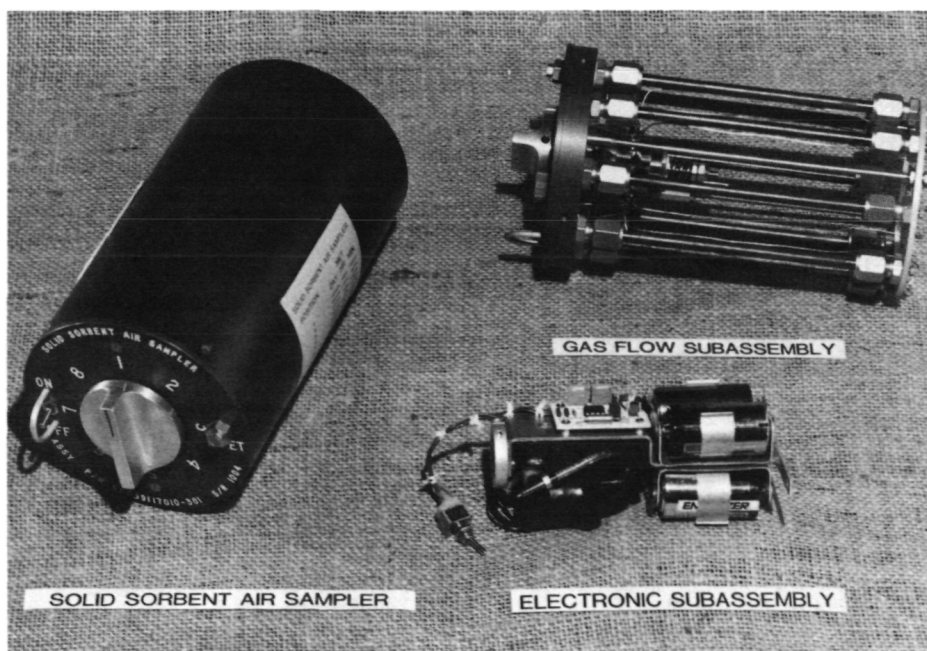
Historically, monitoring of the spacecraft atmosphere consisted of collecting air samples in evacuated cylinders. This static sampling process yields analytical information of the cabin air only at the time the cylinder valve is opened, and the sample is instantaneously collected. The solid sorbent air sampler has been developed to collect gaseous contaminants continually over a 24-hr period and to repeat the cycle for as long as 8 days. This method, which utilizes a solid material to adsorb the trace-level organic compounds, has several inherent advantages. First, with the proper selection of solid sorbent material, the trace volatile organic compounds can be concentrated, while the oxygen and nitrogen, the major volume components of the sample, are not retained. Second, the method is applicable to multiple, continuous, and automated operation. Finally, the increase in size and weight is minimal when multiple samples are collected.

The solid sorbent air sampler is 4.5 in. in diameter and 9.5 in. long, and it weighs approximately 4 lb. It is totally self-contained, requiring neither spacecraft power nor vacuum. Two developmental prototypes and four flight-certified solid sorbent air samplers have been fabricated. The device was first flown on Space Shuttle flight STS 51-B, where it was used to sample the middeck atmosphere. Six composited 24-hr samples were collected during this mission. Laboratory analysis of these samples resulted in the identification and quantification of 47 different trace gas contaminants. Within the scope of its design capabilities, the flight unit performed exactly to specifications. The sampler was also recently flown on STS 51-J and STS 61-A.

The solid sorbent air sampler is a simple, self-contained, and easily operated device that collects a composite sample of the trace-level volatile compounds present in the breathing air of a spacecraft crew cabin. The adsorbed compounds will provide, upon laboratory analysis, an assessment of the quality of the spacecraft cabin atmosphere.

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Solid sorbent air sampler with electronic and gas flow subassemblies.



The Ion Trap Detector, an Air Quality Monitor

TM: Duane L. Pierson/SD
PI: Theodore J. Galen/SD
Reference OSSA 6

The toxicological assessment of the crewmembers' breathing atmosphere is a critical requirement for the continual habitation of the Space Station. The closed environment of the Space Station along with extended crew habitation and the length of time required to evacuate the Space Station will require real-time analysis of the breathing environment. The use of appropriate onboard monitoring systems will allow a realistic near-real-time toxicological assessment for crew safety. This monitoring will enable appropriate countermeasures to be developed and implemented for both short- and long-term solutions to toxicological problems.

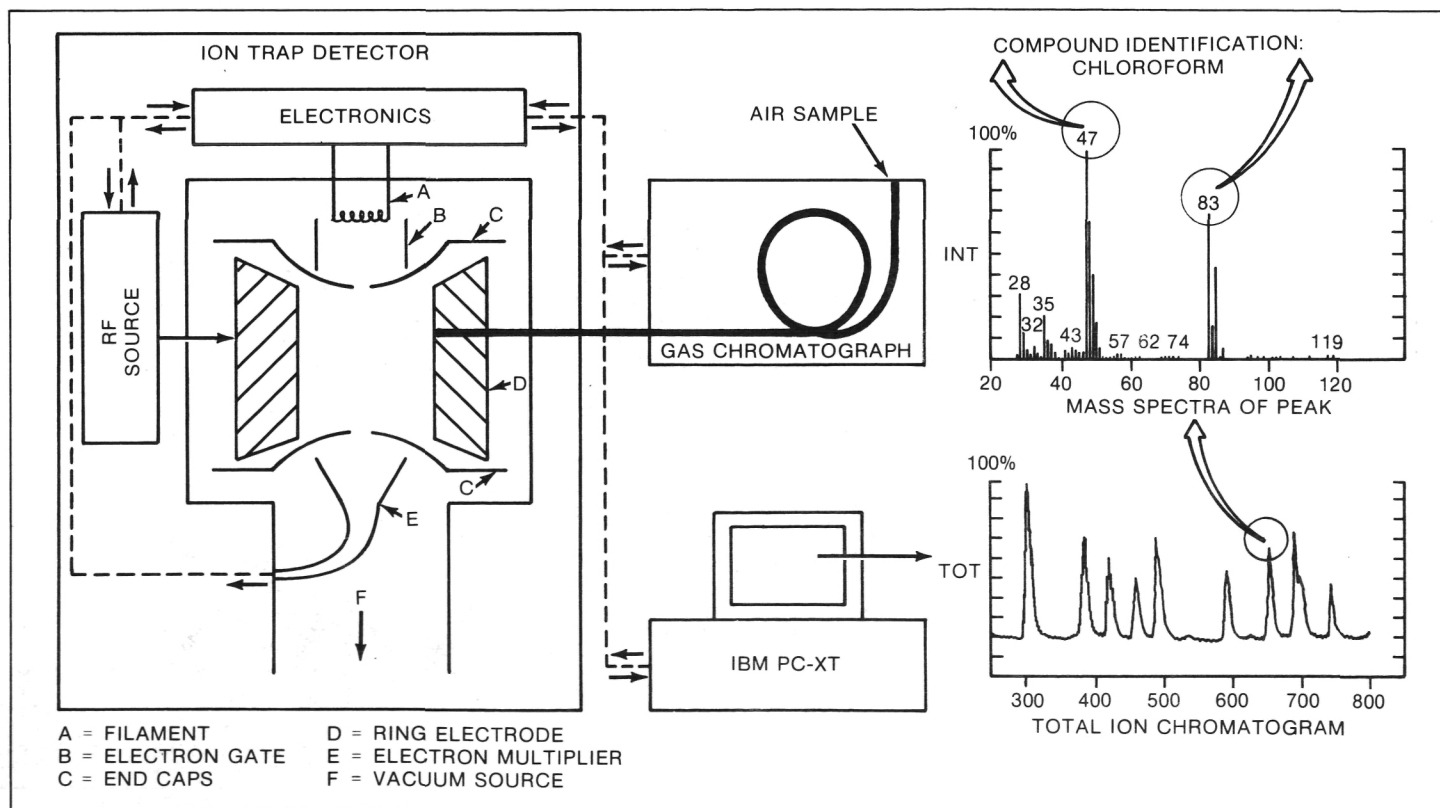
The major analytical instrumental requirements for the Space Station onboard atmospheric analyzer are that it provide unequivocal qualitative analysis

and that it be quantitatively accurate to at least four orders of magnitude in concentration starting from 10 p/b. Only an instrument with a mass analyzer is capable of meeting both of these requirements. The specific instrument of choice is based on the Finnigan-MAT ion trap detector (ITD). It will function as the mass analyzer portion of the system. When coupled with a gas chromatograph (GC), the GC/ITD system would be specifically designed for automated trace-level contaminant analysis.

The development plan for a GC/ITD system, based on the Finnigan-MAT ion trap detector system, is proceeding in three major phases. During phase 1, the laboratory verification, the ITD was coupled with a standard laboratory gas chromatograph, and a complete functional checkout under laboratory conditions was performed. Further research and development (R&D) in this phase will involve adaptation of the laboratory GC/ITD to analysis of concentrated gas and solid sorbent air samples

collected from the Space Shuttle. During phase 2, a breadboard prototype GC/ITD will be constructed. This level of effort has just been initiated in the Toxicology Laboratory at the Johnson Space Center. Considerable hardware and/or software modification and development will be required during this phase. Some of the practical considerations to be addressed in order to arrive at a flight configuration of a GC/ITD include power, vacuum, data handling, the gas chromatograph, consumables, remote sampling, size and weight, and GC/ITD-Space Station interfacing. During the final phase of the R&D, coordination, planning, and fabrication of the flight system GC/ITD with the NASA requirements for safety, reliability, engineering, and quality assurance will be performed.

Schematic of atmospheric analyzer with the ion trap as the mass selective detector.



Carbon Formation Reactor

TM: Robert J. Cusick/EC3

PI: Gary P. Noyes/EC3

Reference OSSA 7

Because of the logistical difficulty of spacecraft air revitalization in long-duration manned space missions, breathing oxygen must be recovered from metabolic carbon dioxide. After removal from the spacecraft atmosphere by any one of several means, carbon dioxide can be reacted with hydrogen to produce methane and water in a Sabatier reactor. The product water can be condensed, separated from the methane, and then electrolyzed into hydrogen and breathing oxygen. To reduce the mass of required water, hydrogen must be recovered from the product methane to supplement the hydrogen from water electrolysis fed to the Sabatier reactor. Also, since the Space Station will likely restrict venting of carbonaceous gases, the methane cannot be disposed of by that method.

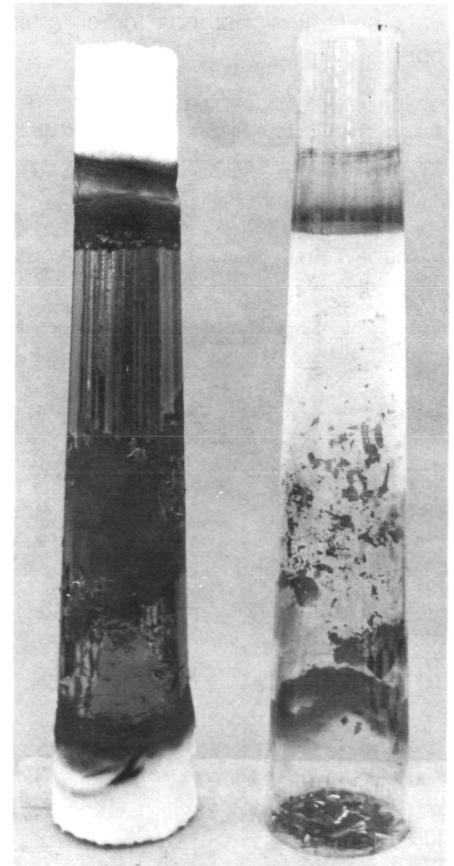
The thermal pyrolysis decomposition of methane into hydrogen and solid carbon utilizing a carbon formation reactor offers a potential solution to the problem. Integration of a Sabatier methanation reactor with the carbon formation reactor will perform the complete carbon dioxide reduction process in a manned spacecraft. The Sabatier reactor produces an exothermic reaction based on a noble metal ruthenium catalyst. In development of a carbon formation reactor, certain new issues must be addressed. The carbon must be periodically removed from the reactor and stored onboard the spacecraft for final disposal. For minimum storage volume, the density of the final product carbon must be maximized. The reactor should be configured to allow for removal of the carbon only to eliminate the penalties associated with reactor replacement. Finally, the pyrolysis reaction should produce high single-pass conversion of methane. Methane pyrolysis is an endothermic reaction and requires a high temperature to obtain significant equilibrium conversion to carbon and

hydrogen. Small-scale laboratory testing has shown that dense pyrolytic carbon could be formed on glass surfaces in a temperature range of 1000° to 1300° C, while only low-density carbon soot was formed in the gaseous phase. Removal of carbon soot from a reactor would pose an undesirable problem in the microgravity of space. Additional small-scale testing showed that a quartz wool packing in a quartz tube reactor resulted in the formation of very dense, crystalline, nonsooty carbon.

Based on small-scale design support test results, a carbon formation reactor was developed and tested. For carbon removal from the pyrolysis reactor, the reactor wall material required a coefficient of thermal expansion lower than that of carbon and the capability for thermal cyclic operation at high tem-

perature. A tapered quartz tube containing quartz wool, sized to contain a maximum of 36 lb of carbon, was chosen as the reactor. This 43-in. reactor incorporates a 25-in. heated zone with a volume of 0.48 ft³, which is packed with 1.65 lb of quartz wool. During tests at 1150° C, a total of 25.7 lb of carbon, representing 15.6 lb of carbon formed per pound of reactor packing, was formed. Methane conversion efficiency remained fairly constant throughout the loading test and varied between 88% and 92%. After the reactor was cooled and the end seals and plates were removed, the carbon/wool rod slid easily from the tube. As shown, the carbon/wool rod was freestanding. The carbon body formed in the heated zone was quite hard and rigid. Film carbon had adhered to the inner wall of the tube in several places and was removed by gentle brushing.

Product carbon and reactor tube.



Man-Modeling and Data Collection

TM: Barbara Woolford/SP22
Frances Mount/SP2
Reference OSSA 8

The human element should be incorporated in spacecraft design beginning with the preliminary design stage. Accomplishing this goal realistically requires models and data describing how the human interacts with his or her environment. This information can be made available to the designer through computer-aided design and computer-aided engineering work stations. A project has been under way for several years to develop new tools for collecting data on man/machine interactions and to use these tools to build a collection of data describing human capabilities and limitations.

Three major tasks will be undertaken in this research project. One is to develop and fly equipment for collecting human force data in zero g; another is to develop and utilize techniques for describing human motion; and the third is to develop and utilize nonintrusive data collection methods for on-orbit operations.

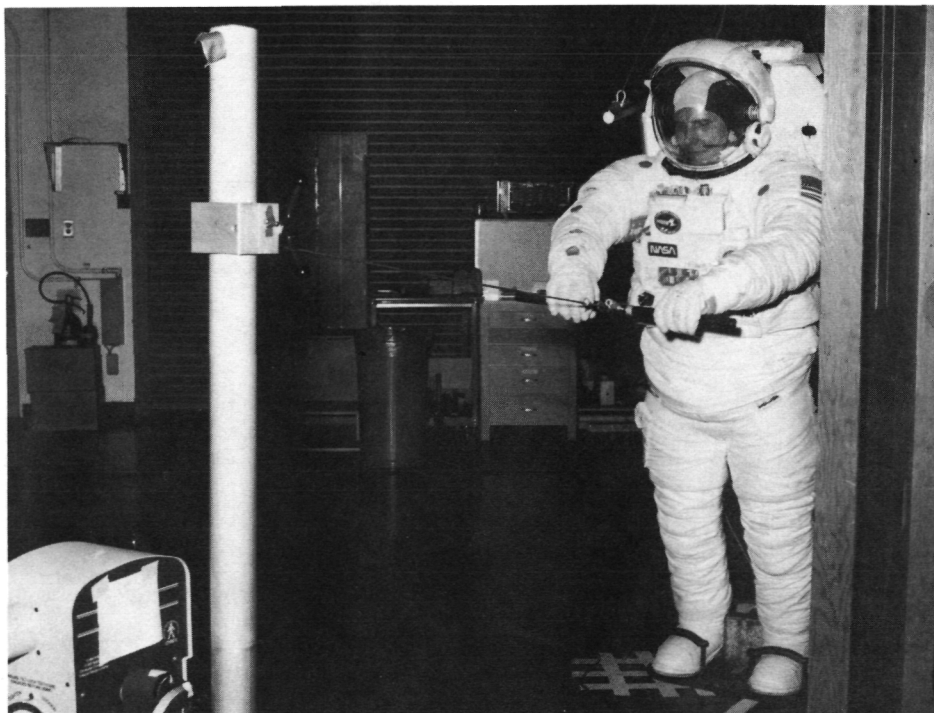
Human force capabilities in zero g depend to a large extent on the restraint methods employed as well as the strength of the individual. To measure force, it is necessary to build footplate and handhold arrangements in addition to a device that will measure the force exerted by the astronaut. The footplate will be instrumented to measure the reaction forces as the astronaut works on the force-torque measurement device. The device is being designed to permit straight line movement to the extent of the astronaut's reach in three directions — push-pull, up-down, and crosswise. It will also measure rotational torque exerted in pitch, yaw, and roll — prying, turning, and twisting — movements. These force components can then be combined to describe strength in other directions by a mathematical model of human capabilities. Illustrated is a space-suited subject pulling on a dynamometer in the Anthropometric Measurement Laboratory (AML) at the Johnson Space Center, where preliminary data are being collected to determine the design parameters for the flight unit.

The AML has developed a technique for automatically collecting data. The data are recorded as a collection of x, y, and z coordinates of points that a subject can reach under a given constraint method (foot restraints, shoulder restraints, etc.). The points are then plotted as a function of height from the floor, and each section of 4 or 5 cm is contoured by hand to describe the reach envelope. This year, research is under way to generate a computer program that will do the contouring and thus enable automating the entire data processing system. The AML is developing equipment to collect electromyographic (muscle nerve firing) data to analyze the components of motion from separate muscles. This analysis will be a step toward developing a muscular model of human strength and motion. Such a model is desired to permit analysis of human capabilities in zero g for use by equipment designers and mission planners.

The objective of nonintrusive data collection is to measure, record, and analyze human factors data with minimal interruption of crew activities. The system will collect three types of data — behavioral, physiological, and biomechanical — using videotaping and filming of crew activities, measurement of bioelectric signals, and measurement of the kinematics and kinetics of crewmembers' bodies.

The infrared physiological data link (IPDL) is a nonobtrusive method of transmitting physiological data via infrared light from a person to a wall-mounted receiver. The IPDL is in the early stages of development. A two-channel prototype unit has been developed and tested. A three-channel prototype unit is in its final stage of fabrication, and the next goal is miniaturization of the prototype.

A suited subject's strength is measured as he pulls on a cable.



Interactive Computer Graphics for Man/Machine Evaluations

TM: Linda Orr/SP22
Reference OSSA 9

The Johnson Space Center (JSC) is responsible for providing human factors analyses in the areas of man/systems integration and man/machine engineering. Two interactive computer graphics programs, PLAID and TEMPUS, are among the tools used to enhance crew productivity by evaluating equipment, vehicle, and operations designs. The PLAID software package models detailed work environments; the complementary TEMPUS program generates realistic man-models for incorporation into PLAID environments.

The research focus for PLAID/TEMPUS software has been to increase man-modeling realism and expand man/machine evaluation capabilities. The TEMPUS man/woman model can be automatically generated from data gathered from specific user inputs. The model created can be a generic (percentile) person, or an individual with specific body segment measurements. Generic persons can be created using the entire anthropometric data base or a desired population within that data base. The human renderings have realistic joint limits and can be articulated within those limits either manually (i.e., direct user inputs) or automatically (i.e., the user commands the model to touch something with his right hand, and the computer calculates the arm joint angles necessary to accomplish the task).

Previous TEMPUS man-models used geometric representations of body segments as mechanical linkages. Although this type of body model, with appropriate joint limits, is sufficient to perform simple reach assessment, a more complex man-model is desirable in many cases (e.g., clearance assessments, design and positioning of body restraints, detailed analysis of man/machine interactions). The newest TEMPUS software includes such a model, called "Bubbleperson." This model uses spherical contours of

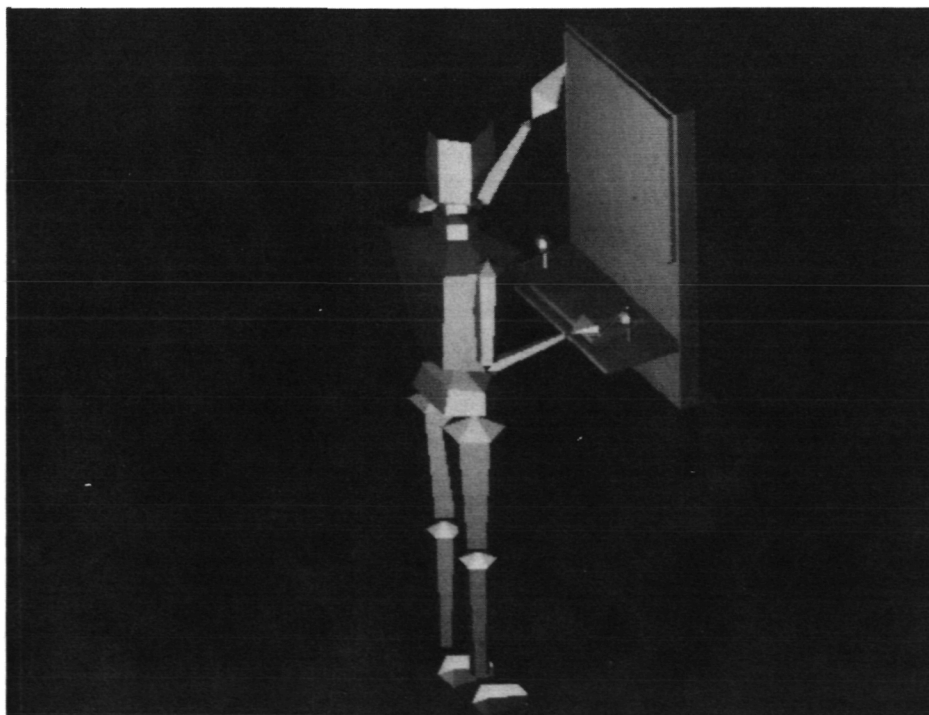
varying diameters to flesh out body segments and incorporates a flexible spine for more realistic movements. Both the geometric man-model and the bubbleperson can be used with PLAID work station models to perform clearance assessments graphically, determine reach envelopes, check visual access, and evaluate man/machine interactions.

To take full advantage of a realistic computer man-model in designing work areas and planning mission operations, the man-model should incorporate strength and motion data. Current research involves defining the types of data needed for strength and motion characteristics and developing mathematical formulas to describe human motion. The necessary data will be collected in the Anthropometric Measurement Laboratory and through in-flight experiments.

An additional development task is to automate the assessment of crew checklist procedures for mission planning support. This task includes devel-

oping capabilities for checklist verification, developing capabilities to evaluate traffic flow and accessibility, and analyzing spacecraft layouts critical to crew performance. Major accomplishments to date include studying flight data files for checklist formats, selecting action verbs (e.g., turn, pull), and defining necessary attributes of selected objects (e.g., are they push/pull buttons, rotary dials). Initial programming of the automated checklist procedure has been implemented, and a sample work panel has been developed for test purposes. At present, the program provides a verbal response, such as TOGGLE 1 — ON, to checklist inputs. The software is being integrated with the TEMPUS/PLAID programs to provide graphic output of checklist procedures. An animation program is being written that will use multiple animation tracks with PLAID/TEMPUS-generated graphics to aid mission planners in improving crew efficiency, avoiding work area bottlenecks, and detecting possible collisions between crewmembers.

Computer man-model evaluating work station interfaces.



Development of a Space Bioreactor

TM: Dennis R. Morrison/SD
Reference OSSA 10

The effort to develop a space bioreactor continues a long-term NASA commitment to biological research and development in space. The earliest efforts showed that some biological substances can be better purified in space using the continuous-flow electrophoresis system (CFES) devised by the McDonnell-Douglas Astronautics Co. The CFES also separated living mammalian cells into fractions, some of which produced larger amounts of medically important substances than others. These results led to the concept of a space bioprocess. Such a process would start with a CFES separation of cells, followed by the culturing of the cells secreting more of the desired drug. The drug would then be isolated from the culture medium and purified by another CFES separation. The ability to culture cells in space would have far-reaching consequences. For example, one-time-only experiments have shown that plant cells are sensitive to weightlessness. A space bioreactor would allow scientists to conduct an

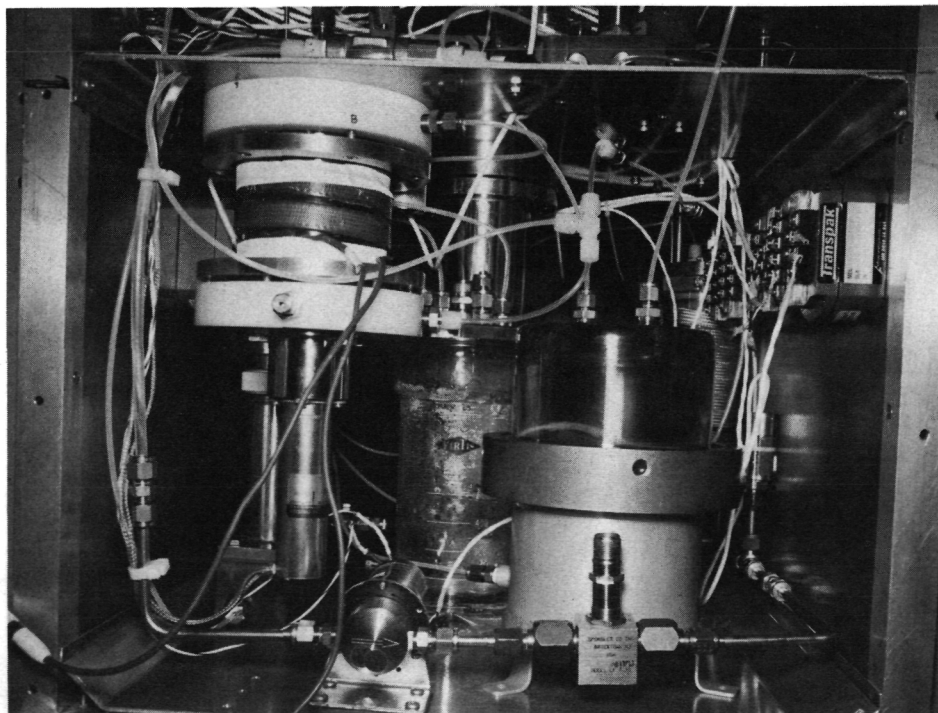
ongoing series of experiments to understand this sensitivity. Such a bioreactor could be one component of a permanent biological research facility in the Space Station.

In the past year, a bioreactor has been built in the laboratories of the NASA Medical Sciences Division at the Johnson Space Center. The design of this reactor represents a significant improvement over bioreactors now in use. This improvement is partly to take advantage of the conditions of space mentioned previously and partly to satisfy criteria imposed by the design of the Space Shuttle Orbiter. Criteria that could result in spinoff technology are compactness, energy efficiency, and automatic operation with minimum operator (astronaut) attention. The basic design is a vessel containing the cells connected to a loop in which a nutrient medium circulates. The loop leaves the vessel through a filter that keeps the cells in the vessel. It returns after oxygenation and nutrient replenishment. In a second loop, accessible from the first, is a device to separate a crude, dilute solution of urokinase. Concentration of this solution will be required before the final CFES purification but is

not part of this project. The space bioreactor assembly has recently been completed. The vessel and the two loops are being tested with water. The automatic process controller is being tested for its capability to control flow and to maintain stable operating conditions. The bioreactor will soon be tested with cells. The objective for next year is to test and improve the design and to definitize operating procedures.

The project goal is to have a space bioreactor ready for Space Shuttle flight in Spring 1987. This Space Shuttle middeck flight bioreactor is designed to sustain a mammalian cell culture. It will produce a solution of urokinase, an enzyme that participates in the dissolution of blood clots. This protein is representative of many drugs that could be produced by the same process. Culturing of mammalian cells is difficult because they are fragile. The culture of human cells in space is expected to give opportunities for exploration of potential benefits such as mixing with very low shear, unique oxygen delivery, and better control of the microenvironment around the cells. Whenever possible, components of the ground bioreactor will be flight-certified and incorporated into the flight unit. The long-range program goal is to incorporate the Space Shuttle experience into the design of the Space Station bioreactor facility.

A view of the space bioreactor. The cell culture vessel is the light-colored unit at the upper left.



Space Sciences and Applications

Solar System Exploration

Summary

Office of Space Sciences and Applications

Solar System Exploration

The exploration of the solar system continues to be pursued by scientists at the Johnson Space Center (JSC) through a wide variety of approaches. Broad questions such as the history of the solar system and the origin and evolution of the planets and their satellites are addressed through the collection and analysis of Antarctic meteorites (see illustration), cosmic dust, and ancient terrestrial rocks and through the continuing analysis of rocks returned from the Moon by the Apollo astronauts. Supporting hypervelocity laboratory work is employed to reproduce petrological processes of planetary crust formation and geophysical processes during impact and crater formation. Hypervelocity impact crater analyses also are contributing directly to our understanding of the survivability of Earth-orbiting satellites in the environment of manmade orbital debris. Planet atmospheres are investigated through ground- and space-based telescopic observations, and Earth-looking remote sensing techniques are used to study global terrestrial ecology.

History of the Solar System

Carbonaceous chondrites and cosmic dust particles represent the earliest and most primitive forms of extraterrestrial material. Recent studies of these materials using several techniques of electron microscopy and X-ray diffraction have shown the presence of primordial minerals which are believed to be formed as a result of high-temperature nebular condensation. Other exciting findings are emerging from analyses of the submicrometer-sized grains.

Summary

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Collecting and cataloging an Antarctic meteorite.

Origin and Evolution of the Planets

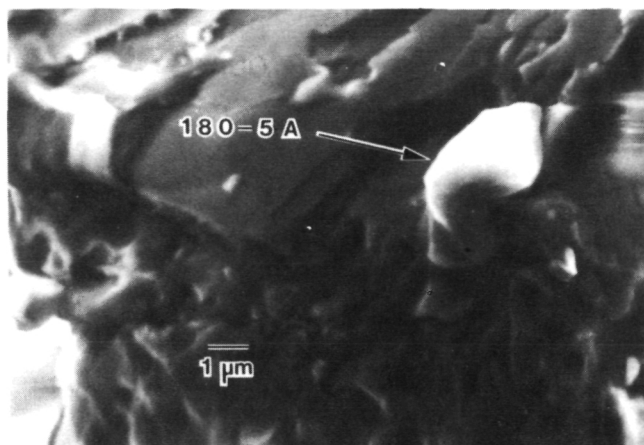
The origin and composition of the Earth's early atmosphere has been of great scientific interest. Carbon and nitrogen in Archean stromatolites and cherts that have remained essentially unaltered since their creation have been subjected to an isotope analysis. Study of these elements, released above 900° C, shows that their isotopic composition has remained constant since about 3.6 Gyr ago despite the many chemical and physical changes in the Earth's biosphere.

In another area of planetary research, strong evidence suggesting martian origin of shergottite meteorites has been accumulated over the past few years. Since the martian regolith is a good storage medium for volatile material, evidence of weathering prod-

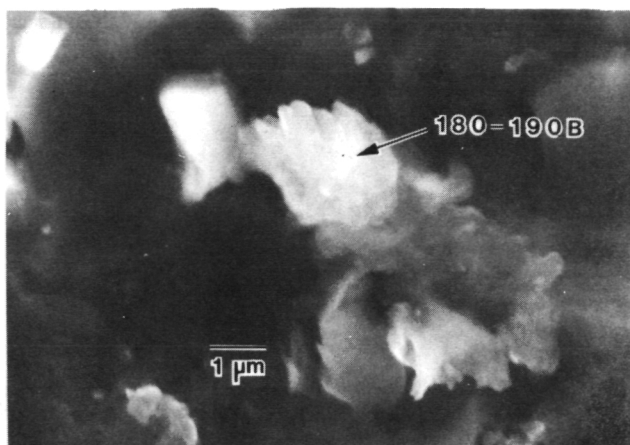
ucts in shergottites should be an indicator of the amounts of water stored in the martian regolith. Recent studies using electron microscopy, X-ray spectrometry, and mass spectrometry on shergottites indicate that glassy inclusions formed in an oxidizing atmosphere that is most likely preterrestrial and entirely consistent with martian origin.

Mercury Atmosphere

Until recently, Mercury, the closest planet to the Sun, was believed to have virtually no atmosphere. Recent telescopic observations, however, reveal emission lines of sodium. These findings indicate that sodium vapor constitutes 90% of the known atmosphere of Mercury. The source of the sodium is likely meteoric material and surface rocks vaporized by meteoroid impacts.



14.0% Fe₂O₃, 2.8 SO₃, < 0.1 Cl



22.3% Fe₂O₃, 3.0 SO₃, 2.8 Cl

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	Cl
80% 5A + 20% 190B [Gooding and Muehow, 1985]	49.4	0.51	11.3	<0.1	15.6	0.71	8.4	7.5	2.1	0.55	1.3	2.9	0.55
Chryse Planitia, Mars [Clark et al., 1982]	48	0.68	8.0	?	19.2	?	6	6.2	?	0.5	?	7.4	0.9

Scanning electron photomicrographs and elemental compositions of unusual mineral grains in a glass-inclusion sample from EETA79001. The grains contain strikingly high concentrations of sulfur and chlorine, and a simple arithmetic mixture of two of the compositions yields a remarkably good match to the bulk composition of fine-grained soil at the Viking landing sites.

Simulation of Planetary Processes

Although much information about the history of terrestrial rocks can be obtained from their overall setting and structure, meteoroids, lunar rocks, and martian rocks come in individual fragments. Only the composition, cooling history, and temperature and pressure relationships allow interpretation of individual specimens. To this end, a laboratory program to study mineral formation and melt crystallization does provide a useful baseline. In particular, simultaneous crystallization of two kinds of feldspar from a melt was observed for the first time by the JSC laboratory and added convincing evidence that the process is a potential origin for several silicate eutectic compositions.

A second important simulation finding in the JSC laboratories deals with fragmentation studies. The material strength of rocks increases with a decrease in temperature. Because most exposed planetary surfaces and asteroids are known to be significantly colder than typical terrestrial laboratories, it is reasonable to assume that fragmentation processes due to hypervelocity impact need to be studied under appropriate thermal conditions. A series of low-atmosphere impact tests conducted at liquid nitrogen temperatures, however, indicates no discernible difference in granite fragmentation from that at ambient temperatures.

Another laboratory simulation task has been directed toward studies of the formation of the lunar regolith. This

very fine soil covers the lunar surface to the depth of several meters. A peculiarity of this regolith is that its mineral and chemical composition changes with the size of the constituent grains. One possible cause is that transport processes are grain size dependent and the observed enrichment of feldspar reflects the addition of nonlocal material, globally distributed from remote crater-forming occurrences. A second theory is that the fractionation is caused by the different comminution rates of the component minerals of a specific rock. Impact experiments performed with a laboratory powder gun support the second theory that the fractionation trends in the regolith are the result of in situ comminution of local rocks.



A sectional view of a perforated 48-lamina plate (magnified 9 times) impacted by a 4.73-mg nylon slug with velocity of 6.23 km/sec. The light area surrounding the perforation shows the extent of the internal damage in the plate. The damage is caused by the delamination and breakage of the laminae.

Effects of Space Collisions on Materials

Because of increasing evidence of collisions between spacecraft and meteoroids and orbital debris, laboratory studies of hypervelocity collisions have significantly gained in importance in recent years. Composite materials used in space applications have been subjected to high-velocity impact analysis at JSC, and the first prediction model for graphite-epoxy hypervelocity impact cratering has been generated. Shown in the figure is a typical case of crater formation and delamination caused by a reflected tensile wave from the back surface.

Global Ecology

During the last year, JSC has conducted research aimed at providing better global estimates of the interaction of forest canopies and the carbon budget through the use of satellite remote-sensing systems. In order to verify the approach, a helicopter-mounted C-band scatterometer measured the backscattered power versus the range in the forest canopies of black spruce, aspen, and jack pine over a northern Minnesota boreal forest area. The results show that key measurements do not change throughout the season as had been anticipated. Implications of these results for

scheduled Shuttle imaging radar C, Canadian synthetic aperture radar (SAR), and European C-band SAR (launch 1989) are likely to be profound.

Supporting JSC In-House Lunar and Planetary Activities

A broad range of topics was considered by participants in a symposium, "Lunar Bases and Space Activities of the 21st Century," organized by JSC and held in Washington, D.C., in October 1984. A major activity in 1985 was the completion of a book with the same title as the symposium based largely on the papers delivered there. The book will be published by

the Lunar and Planetary Institute in December 1985. The topics addressed included, among others, scientific objectives, utilization of lunar materials, design concepts for lunar bases, and political considerations.

Among the papers presented at the symposium were several dealing with the question of Mars exploration, which to many represents the challenging intermediate-term focus for space exploration and expansion of human activity. Based on that perception, considerable effort was expended in 1984 to understand the rationale and requirements for a Manned Mars Program that would lead to a permanent outpost on Mars. In particular, the subject of commonality between lunar bases and manned Mars missions and the question of whether one should precede the other were addressed.

Both a permanent Mars base and a permanent lunar base would have to maximize the utilization of indigenous resources to provide consumables for life support, and both programs would benefit greatly from the production of chemical propellants for transportation between the base and Earth. Four propellant sources on the Moon, on the Mars moons Phobos and Deimos (see illustration), and on Mars have been studied:

1. A lunar oxygen production plant extracting oxygen from lunar ilmenite (FeTiO_3) by a fluidized bed process has been studied in detail and appears feasible for the lunar surface. A major portion of the plant mass is in thermal insulation, a suggestion that substitution of a lunar-derived material for terrestrial insulation is a fruitful subject for further investigation.

2. Initial specifications for a plant to derive liquid hydrogen from the small quantities of solar wind hydrogen that are ubiquitous in lunar surface soil showed that about 10 to 20 times as much material must be mined and processed as in the ilmenite extraction method for oxygen, if the proper proportion of hydrogen to oxygen for cryogenic propellant is desired. This finding has led to studies of beneficia-

tion techniques for separating and concentrating the hydrogen-rich very-fine-grained fractions of the lunar soil.

3. Liquid hydrogen and oxygen can be derived from carbonaceous chondrites, an extraterrestrial material considered a candidate for the composition of the Mars moons Phobos and Deimos. A process of extracting water, electrolyzing it, and liquefying the hydrogen and oxygen can be utilized.

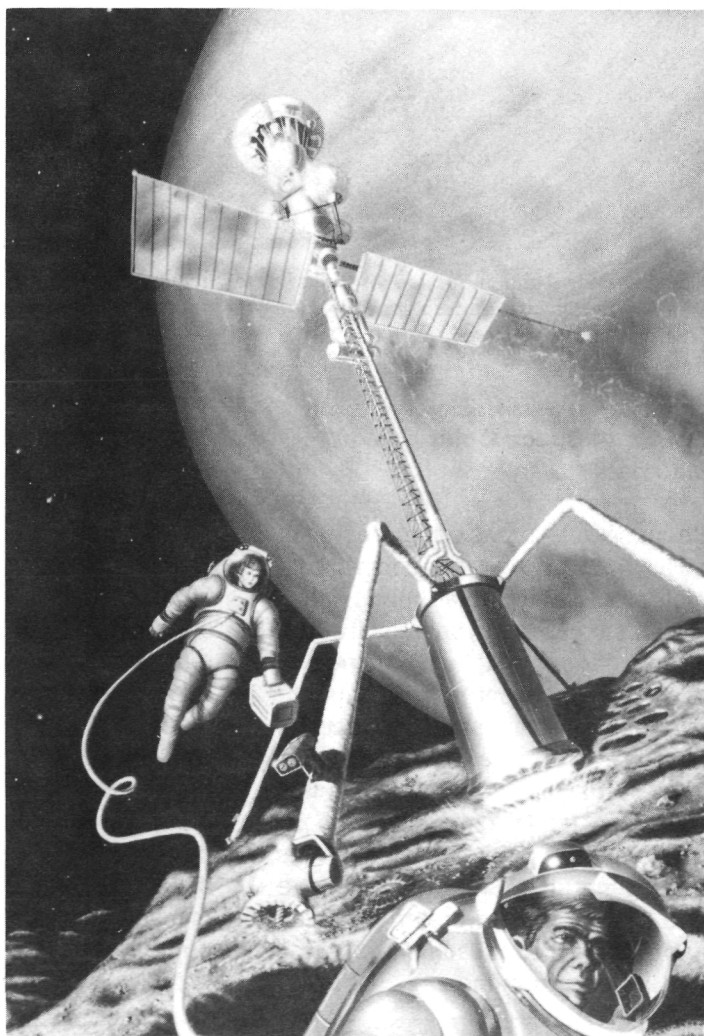
4. Liquid oxygen is the most massive constituent of cryogenic rocket propellant. For early Mars missions, oxygen could be extracted from martian atmosphere by reduction of

carbon dioxide. Concepts for extraction plants on a smaller scale have been developed by the Jet Propulsion Laboratory in conjunction with unmanned Mars sample return missions.

If propellants become available, particularly on the Earth's Moon and Phobos or Deimos, new strategies can be developed for the exploration of Mars. Such strategies might use the Earth-Moon, Earth-Sun, and Mars-Sun libration points, at which gravitational forces are particularly small, as transportation nodes and thus minimize the energy requirements for moving large masses among the Earth, the Moon, and Mars.

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Conceptual Phobos mining team activities.



Space Sciences and Applications

Solar System Exploration

Significant Tasks

Fine-Grained Extraterrestrial Materials

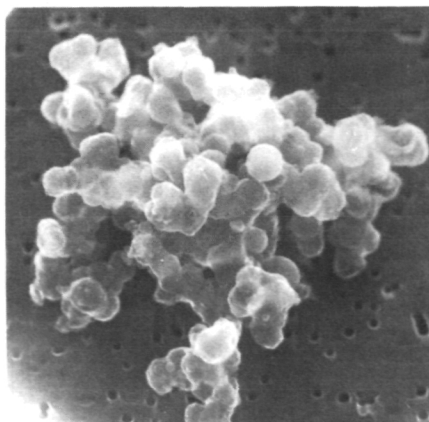
PI: Michael Zolensky/SN2
Reference OSSA 11

The primary sources of information about the composition and chemistry of the other bodies of our solar system are meteorites, returned lunar specimens, and cosmic dust particles collected from the Earth's stratosphere. These samples contain the recorded history of our solar system. In support of the belief that all the bodies of our solar system formed from aggregating dust-sized particles, much of the important information about this process would be revealed if the pristine fine-grained phases remaining in extraterrestrial material could be characterized. In addition, we can gain some idea of the nature of the weathering cycles on other planetary bodies and asteroids through an examination of the alteration products of these pristine extraterrestrial phases. This research involves characterization of the most primitive of extraterrestrial materials, the carbonaceous chondrites and cosmic dust particles. Individual mineral grains in these samples are commonly only a few hundreds of angstroms to a few micrometers in diameter. The techniques used in this study for the identification of these extremely fine-grained minerals are analytical electron microscopy, high-resolution transmission electron microscopy (HRTEM), and X-ray micro-diffraction.

The first minerals to condense out of the cooling solar nebula are believed to have been corundum (Al_2O_3), hibonite ($\text{CaAl}_{12}\text{O}_{19}$), melilite ($\text{Ca}_2(\text{Mg,Al})\text{Si}_2\text{O}_7$), and spinel (ideally MgAl_2O_4). As the temperature of the cooling gas-rich nebula fell further, these early formed phases would have been replaced by minerals that are more stable at the lower temperature regimes. If, however, these early formed minerals were in some way shielded from reaction with the cooling nebula, then they might have been preserved. We have recently identified these primordial phases within cosmic dust particles for the first time. Most of these

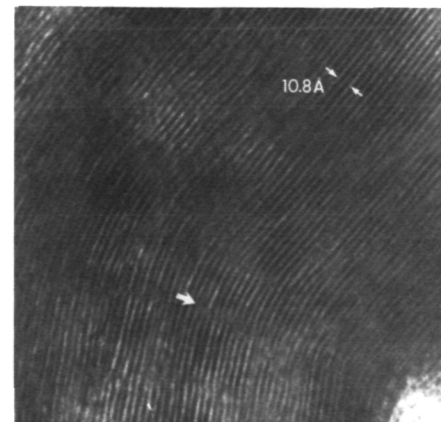
particles are compact masses of submicrometer-sized grains and were probably incorporated into meteorite parent bodies. In this scenario, the individual grains separated from the meteorite during its passage through the Earth's atmosphere. One unique particle, however, was found to be a porous aggregate of micron-sized anhedral corundum grains, resembling a string of beads. This necklace texture is identical to the morphology produced by condensation from a gas, a similarity which supports the conclusion that this particle is a remnant high-temperature nebular condensate. This particle appears too porous to have ever been incorporated into a meteorite parent body. It is suggested that this particular grain may have been protected by a mantle of ices within a cometary nucleus and thus may have avoided a major source of processing and alteration after condensation. This particle is probably one of the best samples we have yet obtained of the earliest stage of our solar system.

Cosmic dust particle W7029 E12, which is a porous aggregate of micron-sized corundum grains. This particle appears too porous and delicate to have survived incorporation into a meteorite parent body and consequent ablation from it. Therefore, it is suggested that this grain may have been protected by a mantle of ices within a cometary nucleus. The particle measures approximately 10 μm across.



Major fine-grained components of the CM carbonaceous chondrites are the so-called poorly characterized phase (PCP) minerals. As the name suggests, characterization of these minerals has eluded researchers. A dominant variety of PCP has a rolled or cylindrical morphology and consists predominantly of iron, sulfur, nickel, magnesium, and hydroxide. This type of PCP is characterized by a basal atomic lattice spacing of 10.8 Å. We have recently discovered that this type of PCP is actually an iron-rich variety of the rare terrestrial mineral tochilinite. Confirmation of this belief came when we observed by HRTEM the identical 10.8-Å basal lattice spacing of both terrestrial and extraterrestrial tochilinites. Research indicates that terrestrial tochilinite forms from the low-temperature aqueous alteration of magnesium-iron silicates under conditions of low $f\text{O}_2$, high $f\text{S}_2$, and high pH. The indication is that the extraterrestrial iron-rich tochilinites formed under similar conditions.

An HRTEM image of terrestrial tochilinite showing the curved basal lattice planes. This sample was a complete cylinder of tochilinite before sectioning and sample preparation for the TEM. Note the 10.8-Å basal lattice spacing, which is characteristic of both the terrestrial and the extraterrestrial tochilinites.



Earth's Early Atmosphere as Seen in Ancient Sediments

PI: Everett K. Gibson, Jr./SN4
Reference OSSA 12

The origin and evolution of the Earth's early atmosphere has long been a topic of great interest, but determination of actual compositions over geologic time has been a vexing problem. However, recent systematic studies of stromatolite deposits by the Precambrian Paleobiology Research Group have extended our knowledge of Archean ecosystems. It has been shown that many stromatolite deposits have undergone negligible alteration since the time of formation. The discovery of primary fluid inclusions within unaltered 3.5-Gyr-old Archean sediments and the observation that the 3.3-Gyr-old Barberton, South Africa, cherts have remained closed to argon loss since their formation and have not been subjected to thermal metamorphism suggest that an opportunity exists for the direct measurement of the volatile constituents present at time of formation.

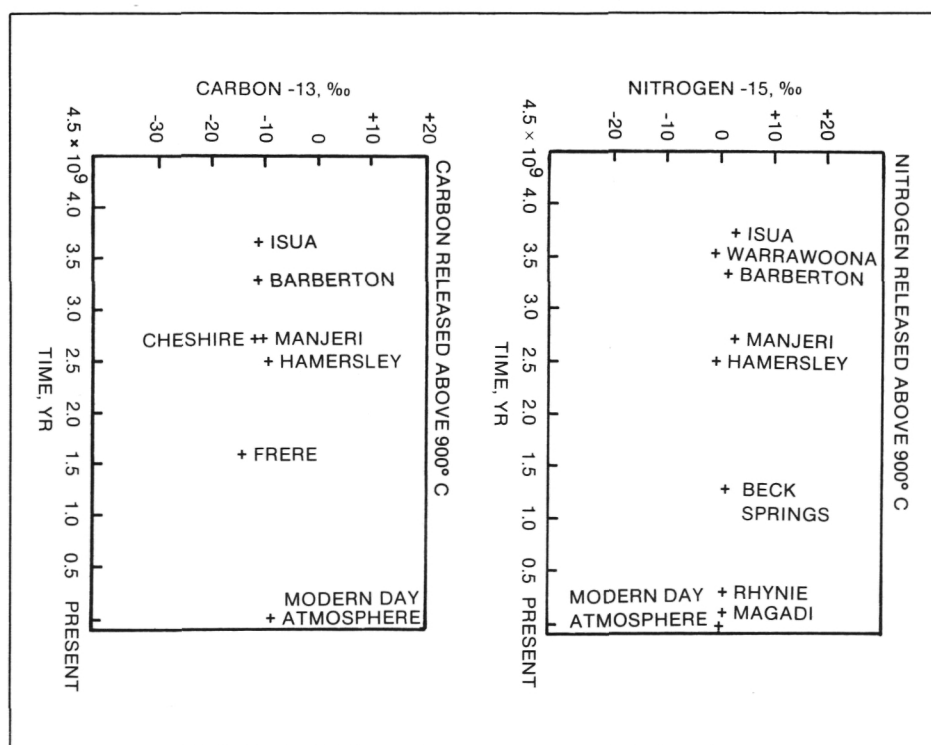
Of primary interest to our study has been the possibility that the stromatolites and other Archean sediments might retain a vestige of the atmosphere and hydrosphere and thus provide an indication of the variations in carbon dioxide and nitrogen isotopic compositions over time.

A suite of essentially unaltered Archean stromatolites and cherts of different ages and geologic sites has been analyzed for carbon dioxide and nitrogen compositions by the stepped combustion extraction technique utilizing static mass spectrometers for the isotope measurements. Studies of modern-day sediments have shown that both nitrogen and carbon associated with unmetamorphosed organic matter is released in the 300°- to 700°-C interval during combustion. Release of carbon from carbonates and graphite is completed at a temperature below 900° C. Pyrolysis studies of Archean cherts and sediments have shown that modern-day atmospheric argon is lost below 900° to 1000° C and that the

argon released above this temperature interval represents samples of trapped early atmospheric argon. In studies at the Johnson Space Center, carbon dioxide and nitrogen released above 900° C were assumed to represent gases trapped during the formation of the sediments, and they may be a remnant of atmospheric gases during Archean times.

Isotopic analysis of nitrogen released at elevated temperatures from samples ranging in age from 1.7 to 3.5 Gyr (i.e., Frere, Hamersley, and Barberton formations) produced values ranging from +6% to +1%, which are similar to the modern-day atmospheric nitrogen value of 0%. The nitrogen released from the Archean sediments occurs in at least three forms of different isotopic compositions, ranging from -30% to +18%. Carbon dioxide released above 900° C from six sediments (Frere, Hamersley, Manjeri, Cheshire, Barberton, and Isua formations) ranged from -7% to -14%, and most of the values were similar to the present-day atmospheric value of -8%. At lower temperatures, carbon isotopic compositions ranging from -7% to -56% were observed. The -56% value was obtained from the analysis of kerogen extracted from the Fortescue formation. Existing evidence suggests that many of the Archean sediments contain secondary carbon and nitrogen of a postdepositional origin in addition to the trapped atmospheric components and indigenous organic material incorporated at the time the sediments were consolidated. From the analysis of primary gases trapped within Archean sediments, it appears that the carbon dioxide and nitrogen isotopic compositions present within primary inclusions are essentially identical to modern-day atmospheric carbon and nitrogen. This similarity suggests that despite the numerous chemical and physical changes which have occurred within the atmosphere and hydrosphere of the early Earth, the isotopic compositions of the carbon and nitrogen components have not changed.

Summaries of isotopic compositions for carbon and nitrogen released above 900° C for a variety of Archean sediments of different ages. Note the similarities to the modern-day atmosphere.



Search for Martian Weathering Products in Shergottite Meteorites

PI: James L. Gooding/SN2
Reference OSSA 13

Although considerable circumstantial evidence exists for the derivation of shergottite meteorites from Mars, the first direct evidence for their martian origin came from a discovery in the shergottite EETA79001 found in Elephant Moraine, Antarctica (A79001). This shergottite contained trapped gases that resembled the martian atmosphere in both elemental and isotopic composition. That important result was obtained in 1982 by D. D. Bogard of the Lyndon B. Johnson Space Center and served to inspire further detailed studies of EETA79001.

If, in fact, EETA79001 and other shergottites are samples of the surface or near-surface materials of Mars, other physical evidence might occur in the meteorites that would indicate the nature and extent of interactions between the source rocks and the chemically reactive martian atmosphere. The discovery of martian weathering products in the meteorites might provide important new insights into the possible role of the regolith (the layers of rock fragments and soils that cover the martian surface) as a reservoir for water and other volatile materials on Mars. Pulverized igneous rocks, comparable to the Moon's regolith, can store volatile materials by physical adsorption on particle surfaces, whereas secondary minerals or mineraloids, comparable to the Earth's regolith, can act as physical sorbents and, through chemical bonding and weathering, can act as more irreversible sinks for volatile materials. Therefore, the types and abundances of weathering products on Mars should exert a major influence on the forms and amounts of water that might be hidden in the regolith.

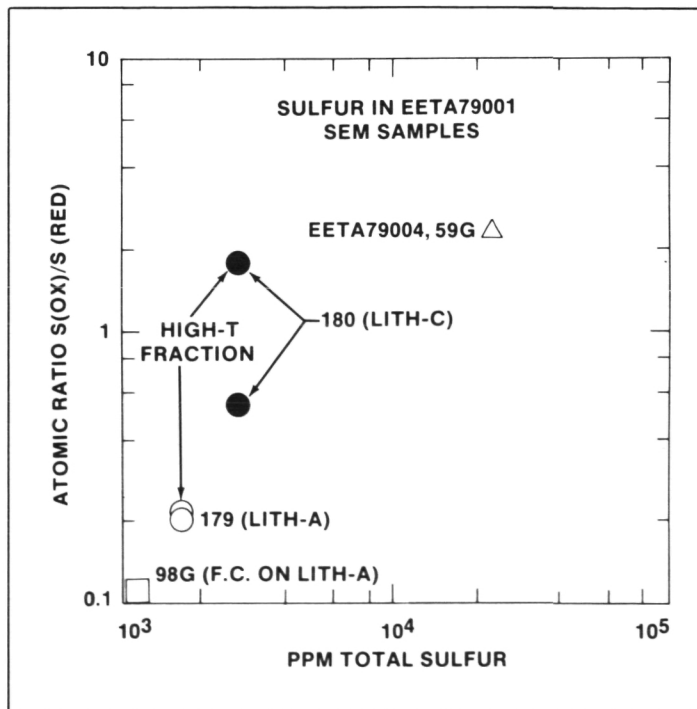
Previous measurements of trapped gases in EETA79001 indicate that the martian component is not homogeneously distributed but is concentrated in peculiar glass-rich pockets that occur as ovoid to irregular inclusions within

the meteorite. Recent work by principal investigator James L. Gooding and Professor D. W. Muenow of the University of Hawaii — using scanning electron microscopy (SEM), energy-dispersive X-ray spectrometry, and high-temperature mass spectrometry — has shown that the same glassy material also contains sulfate sulfur and traces of sulfur-rich aluminosilicate minerals or mineraloids of probable preterrestrial origin. Apparently, the glassy inclusions formed in an atmosphere that was sufficiently oxidizing to form sulfate from sulfide.

The additional enrichment of chlorine in one variety of aluminosilicate marked a possible petrogenetic link with the sulfur- and chlorine-rich, fine-grained materials that cover much of the martian surface at the two Viking landing sites. Unfortunately, the water contents of the tiny grains in EETA79001 could not be measured, although additional analyses are planned for new samples.

One pervasive problem in the use of EETA79001 to derive information about martian gases and weathering products is that the rock contains a substantial background of gas-rich weathering products of Antarctic origin. Consequently, great care must be taken to ensure that Antarctic effects are not mistaken for martian effects in the study of volatile components. Parallel analyses of control samples, including heavily weathered exterior chips of EETA79001 and of EETA79004, a eucrite meteorite found nearby in Antarctica, produced evidence against Antarctic weathering as the source of oxidized sulfur and sulfur-rich aluminosilicates. Therefore, it is likely that most, if not all, of the oxidized sulfur in the gas-bearing glass is preterrestrial in origin. Results obtained to date are entirely consistent with the origin of EETA79001 on the surface of Mars.

Abundances and relative oxidation states of sulfur in host-rock (lith-A) and glass-inclusion (lith-C) samples of shergottite EETA79001. Sulfur pyrolyzed from lith-C occurred mostly as H_2S and S_2 , whereas much of the sulfur pyrolyzed from lith-C was SO_2 . The high oxidation state of sulfur in eucrite EETA79004 is caused by Antarctic-originated gypsum. However, the lith-C sample was verified by electron microscopy to be free of gypsum and other recognizable products of Antarctic weathering. Therefore, the oxidized sulfur in lith-C must be preterrestrial in origin.



Discovery of Sodium in the Atmosphere of Mercury

PI: A. E. Potter/SN3
T. H. Morgan/SN3
Reference OSSA 14

During investigations of the filling-in of Fraunhofer lines in the spectrum of Mercury-reflected sunlight, significant amounts of sodium vapor were discovered in Mercury's atmosphere. The sodium was detected from emission lines found in Mercury spectra which were measured using the University of Texas 2.7-m telescope at the McDonald Observatory. The sodium spectrum is outside the range of the Mariner 10 ultraviolet spectrometer and, consequently, was not detected when the Mariner 10 spacecraft flew by Mercury in 1974.

The figure shows the sodium D line region in the Mercury spectrum for an observation performed at 2020 universal time (UT) on January 3, 1985. The sodium Fraunhofer absorption lines in Mercury-reflected sunlight were Doppler-shifted redward 0.86 Å because of the net effect of the Sun-Mercury relative velocity of 9.4 km/sec and the Mercury-Earth relative velocity of 34.6 km/sec at the observation time. Sharp emission lines on the blue side of the two sodium D absorption lines were attributed to resonance scattering of sunlight by sodium vapor at rest with respect to Mercury. The Doppler shift of the emission lines relative to the solar absorption lines (0.19 Å) was consistent with this interpretation. The measurements were repeated on January 4 and January 6, with sodium present each time. The measurements were also repeated in May, July, and November 1985 with similar results.

The spectral data were analyzed to estimate the abundance of sodium vapor on Mercury (see table). The equivalent widths of the lines were calculated by measuring the area bounded by the emission line profile, and this area was used to determine the equivalent width relative to the solar continuum outside the sodium Fraunhofer lines. The ratios of D₂ to D₁,

were corrected for unequal solar intensity at the location of the two lines and represent the ratios that would have been observed if the solar intensity had been the same for both lines. The abundance of sodium vapor was derived from the line ratios by the application of radiative transfer theory.

The average sodium vapor column density of the three measurements made in January was 8.1×10^{11} atoms/cm². With an assumed subsolar temperature of 575 K, this density corresponds to a surface density at the subsolar point of 1.5×10^5 atoms/cm³ and a pressure of 1.2×10^{-11} millibars. These values establish sodium vapor

as the major constituent of the Mercury atmosphere, since the next most abundant atmospheric gas is helium, with an abundance of about 4.5×10^3 atoms/cm³. More than 90% of the known atmosphere of Mercury consists of sodium vapor.

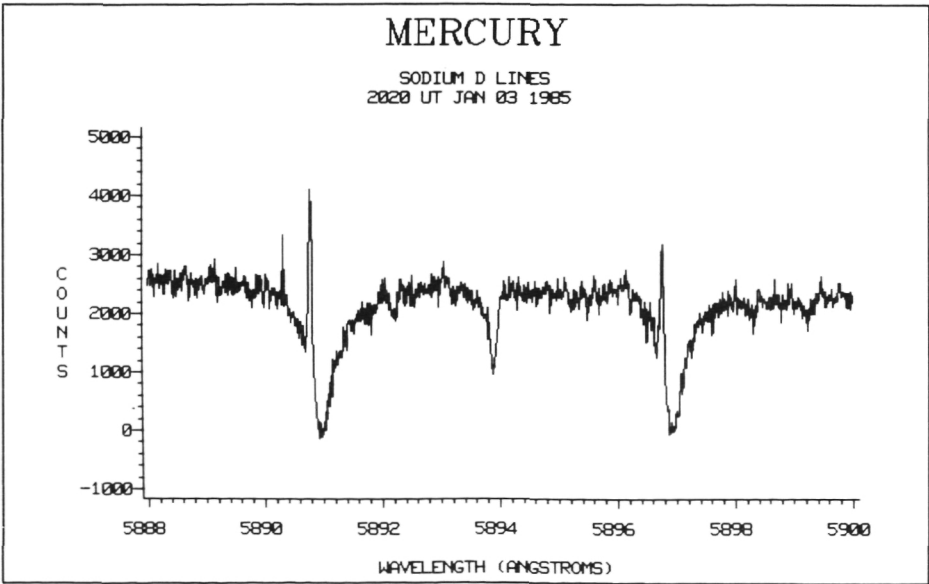
The source of the sodium atmosphere appears to be meteoritic material and surface rocks vaporized by in-falling meteoritic material. The observed atmosphere represents a steady-state balance between supply from meteoroid infall and loss from ionization by solar ultraviolet radiation followed by trapping of the ions in the solar wind.

Sodium Resonance Radiation From Mercury. Data Are Reported as Mean Standard Deviations Derived From Noise in the Continuum Spectrum.

Date, 1985	Equivalent width, mÅ				Ratio ^a		Column density, atoms/cm ²	
	D ₁		D ₂					
Jan 3	66	2	83	3	1.48	0.09	7.0 × 10 ¹¹	2.0 × 10 ¹¹
Jan 4	50	2	60	2	1.41	0.08	8.8	2.2
Jan 6	48	2	58	2	1.42	0.08	8.5	2.2

^aRatio of D₂ to D₁, corrected to equal intensities of solar illumination at the sodium lines.

Spectrum of Mercury in the D line region.



Eutectic Growth of Feldspar Minerals From Silicate Melts

PI: Gary E. Lofgren/SN4
Reference OSSA 15

Intergrowth textures in igneous rocks, such as quartz-feldspar intergrowths in granophyre and graphic granite, are often compared with eutectic crystallization products in metallic systems. These comparisons have led to the conclusion that certain intergrowth textures form by simultaneous crystallization from the melt. The growth mechanisms and the variable compositions of the intergrowths, however, are not well understood.

Eutectic crystallization has been studied in great detail in metallic systems. Experimental studies in the last two decades have shown not only that eutectic crystallization products display great variability in growth properties and resulting textures but, more importantly, that off-eutectic compositions are common as crystalline products and result from kinetically controlled growth. Furthermore, varying the off-eutectic composition by controlling the growth is possible.

Experimental studies of eutectic crystallization in silicate melts are difficult because of the strongly anisotropic growth of silicates and the high activation energies associated with nucleation. Eutectic intergrowths of quartz and feldspar are encouraged by low quartz melt entropy values, which reduce the tendency for facet formation, but are complicated by large differences in crystallographic structure. Despite the difficulties, there has been limited success in growing these textures from the melt. High-temperature feldspars have high melt entropies, but share a common crystallographic structure. This common structure allows an epitaxial relationship between the constituent parts of an intergrowth structure and, thus, a lower nucleation barrier. Intergrowths of two feldspars, therefore, should occur more readily than those of quartz and feldspar.

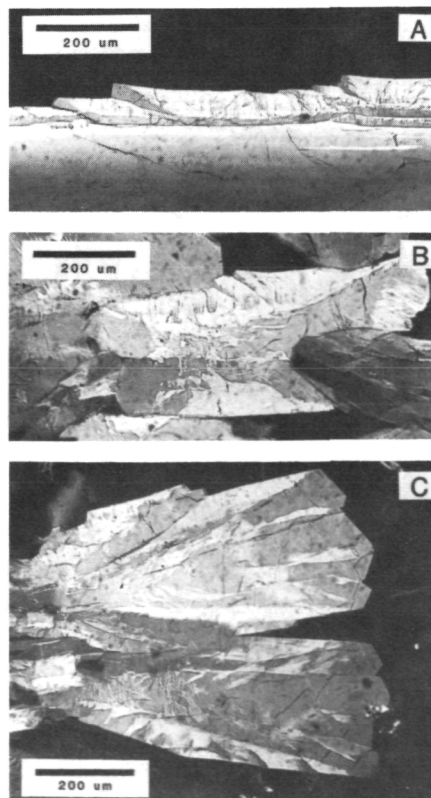
Convincing experimental evidence for simultaneous crystallization of two

feldspars from the melt was first observed in experiments done in the Johnson Space Center laboratory. Although the suggestion that composite feldspars could grow from the melt was not entirely new, this experimental evidence brought about some debate as to its primary nature. Because subsequent laboratory studies have shown that simultaneous, two-feldspar crystallization occurs spontaneously in a wide range of ternary feldspar compositions at moderate cooling rates, the process must be considered a potential origin for intergrowths of certain types of feldspars as well as for other silicate eutectic compositions.

The composite crystallization occurs primarily as a lamellar intergrowth of oligoclase and sanidine having a plane front and a much higher rate of growth than do single phases. This growth is controlled by transverse diffusion across the interface and removal of latent crystallization heat. Off-eutectic crystallization creates a diffusive boundary

layer of solute-enriched liquid that can cause rhythmic compositional changes and banding during growth. The lamellar products show systematic compositional variations in the growth direction as well as gradual changes across individual facets following variations in the local supercooling.

A patchy intergrowth is formed when the preferential growth of sanidine in the crystallographic a/c direction is combined with simultaneous growth of a composite product in the crystallographic b direction. Depending on the relative growth rates in these two directions, the product develops a featherlike structure which is dominated by either potassium-enriched feldspar or plagioclase with subordinate amounts of sanidine intergrowth. Because of the simultaneous growth of two components in the noncoupled intergrowth, the boundaries between the constituent phases are irregular and, unlike the coupled intergrowth, show no reference to particular crystallographic planes.



Stages of patchy intergrowth formation. Sanidine (dark gray) grows preferentially in lateral (horizontal) direction, whereas a composite, oligoclase-rich product (light gray) dominates the vertical growth, normal to the interface.

Collisional Disruption of Cold Rock Targets

PI: Mark J. Cintala/SN12
Friedrich Horz/SN4
Reference OSSA 16

Virtually every impact experiment conducted in the laboratory has taken place at room temperature, but almost every planetary surface in the solar system is drastically colder. This disparity leads to questions regarding the extrapolation of conclusions from laboratory work to actual conditions in space. In particular, it is known that as the temperature of rock decreases, its strength as indicated by various measures increases. Since the outcomes of collisions are strongly dependent on the strength of the target in many cases of interest — the destruction of asteroids, of boulders on planetary surfaces, or of ring particles, for instance — it is reasonable to expect that the temperature of such a target would exert some influence on the ease with which it is destroyed by impacts.

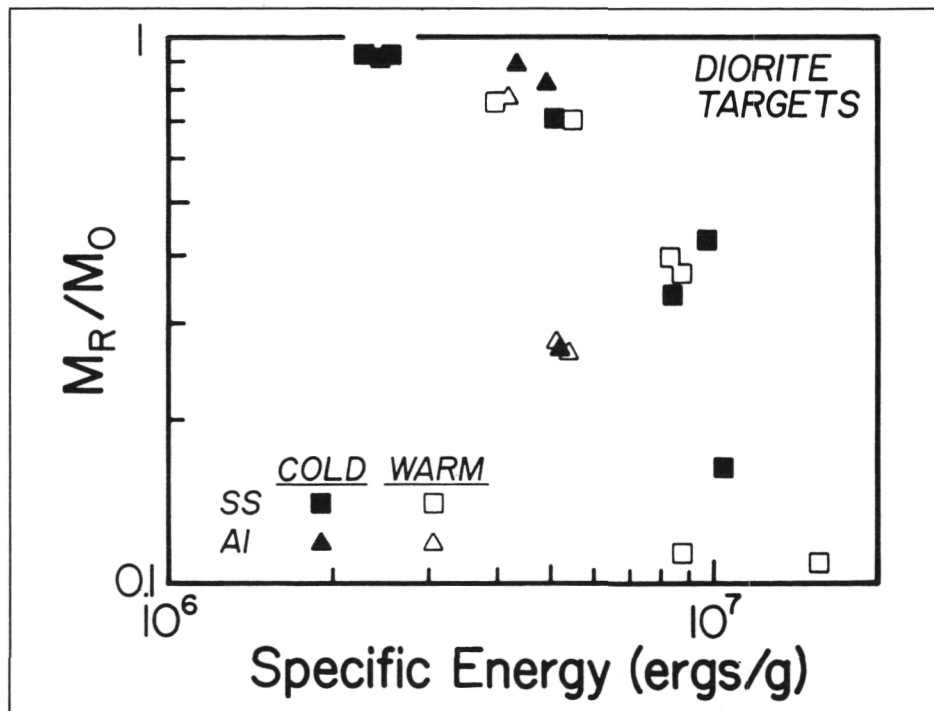
A series of experiments was conducted in an effort to evaluate the effects of target temperature during impact with solid rock (granite). These unusual experiments required some exceptional procedures. Impact experiments must be conducted under very low atmospheric pressures to minimize drag effects on both the projectile and the ejected material; at the same time, the space environment is simulated more effectively. Liquid nitrogen (LN_2) baths were employed to chill the target rocks to temperatures characteristic of most of the solid objects in the solar system, about 100 K (-279°F). Since LN_2 freezes at about 0.1 atmosphere of pressure and the target rocks were kept in the bath as the impact chamber was evacuated, the LN_2 had to be removed to prevent the target rock from being encased in a solid block of nitrogen during the experiment.

Two subsets of experiments were conducted: one involved the formation of craters in large target slabs, and the other addressed catastrophic disruption

— that is, the destruction of discrete targets of known shapes and masses. Among the variables used in the analysis were crater size and shape, displaced mass, grain size distributions, mean grain size of the ejected or displaced material, remaining mass of the target (in the case of the disruptive subset), and the amount of newly formed surface area (a measure of the degree of pulverization of the target). The illustration is an example of the type of data obtained in this study and is also a good reflection of the other parameters utilized in the analysis. If one of the targets of different temperature had been stronger than the other, the remaining masses after an impact of a given energy would have differed systematically.

As is apparent in the figure, both the warm and the cold targets responded in a similar manner over a wide range of impact energies. The fact that none of the other variables showed a consistent or noticeable temperature dependence leads to the conclusion that the low temperatures prevailing in the rest of the solar system contribute little, if anything, to variations in the mechanical effects of impact into rock. Complications due to low target temperatures when rock is the target thus appear to be negligible, at least on small scales.

The mass of the largest remaining fragment (M_R), expressed as a function of the original target mass (M_O), plotted as a function of the impact energy (ergs) per unit mass of the original target (g). The projectiles used were stainless steel (SS) and aluminum (Al). The scatter in the data is typical of such experiments and is due predominantly to the random orientation and failure of the minerals comprising the rock.



Because water ice, the dominant constituent of solid bodies in the outer solar system, undergoes more radical changes in strength as the temperature drops, these results should not be applied to ice. A similar experimental series using water ice as the target over a range of temperatures is being planned. Temperature-related differences are expected to be more noticeable in ice than they were with the crystalline rock targets.

Regolith Evolution Experiments

PI: Friedrich Horz/SN4

Mark Cintala/SN12

Reference OSSA 17

The surfaces of atmosphereless bodies such as the Moon, Mercury, and numerous asteroids are continuously bombarded by micrometeoroids that generally have a mass of less than 1 g. Such objects typically will not survive entry on bodies where an atmosphere is present. On airless bodies, however, such particles may constitute an important, if not dominating, erosive force. High-speed micrometeoroid impacts cause cratering in bedrock and collisional breakup of surface boulders. These processes ultimately lead to the buildup of a fine-grained surface deposit called regolith or soil. On the Moon, this soil layer is on the order of 5 to 10 m thick and has median grain sizes between 50 and 100 μm . Although detailed understanding of regolith processes is interesting and important alone, it is also significant in the interpretation of remotely sensed mineralogic and geochemical information that generally refers to the uppermost 10 cm (or less) of a planet's surface.

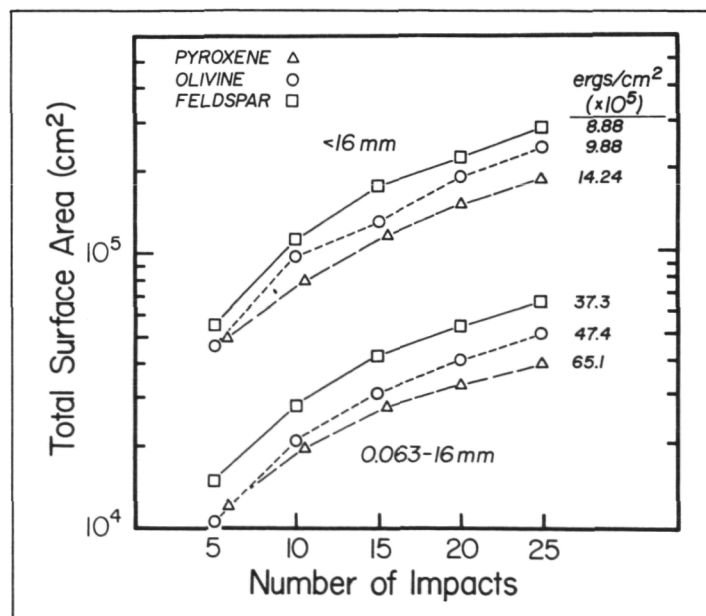
A somewhat puzzling feature of the regolith process is currently the subject of some lunar regolith studies. The extremely fine-grained fractions ($<20 \mu\text{m}$) are of different mineralogic-petrographic makeup and thus are also of different chemical composition than are the coarser fractions (i.e., $>100 \mu\text{m}$). The fine grain sizes are fractionated relative to the bulk soil and are enriched in feldspathic components. Two processes are possible causes of this fractionation: (1) the enrichment of feldspar reflects the addition of material from nonlocal sources, or (2) the component minerals making up a specific rock display differential comminution behavior.

The second hypothesis was tested in the laboratory. Targets composed of either feldspar, pyroxene, or olivine, the most prominent lunar minerals figuring in the ongoing debate, were repetitively impacted by means of a powder gun. The

larger targets weighed 4000 g and initially ranged from 16 to 32 mm; each target was impacted 25 times. The targets were sieved, and data from the grain-sized fractions were converted into surface areas. Since the kinetic energy of the impactors (stainless steel spheres of 6.35 mm diameter traveling at 1.4 km/sec) is known, the comminution efficiency may be expressed simply in terms of absolute energy required to generate a specific amount of new surface area. Comminution efficiency is stated as ergs/cm^2 . Data for two grain size intervals are illustrated. The data labeled $<16 \text{ mm}$ include grain sizes less than 63 μm in diameter; the exact grain size distribution of the $<63\text{-}\mu\text{m}$ materials was not determined and was modeled according to lunar grain size data. Because much of the absolute new surface area resides in these numerous small particles, the results are somewhat model-dependent. The data for 0.063- to 16-mm particles, however, are free of any model assumptions and are based on measured grain size distributions.

Apparently, feldspar does indeed comminute with greater ease than do olivine and pyroxene. In a volumetric sense, feldspar and pyroxene are much more prominent in lunar rocks than is olivine. Therefore, the major fractionation trend observed in lunar soils is predominantly a function of the relative behavior of feldspar and pyroxene. The experimental findings lend credence to the hypothesis that the fractionation trends observed in lunar regolith fines are the result of in situ comminution of local rocks rather than the result of a significant lateral transport regime during large-scale impacts at distant locations.

Cumulative plots of a specific free surface area generated during repetitive impacts into feldspar, olivine, and pyroxene targets.



Hypervelocity Impact Studies of Composite Materials

PI: Jeanne Lee Crews/SN12
Reference OSSA 18

Composite materials are being used for space applications on an increasing scale. In orbit, these materials are exposed to potentially damaging hypervelocity impacts from meteoroids and orbital debris. The relative impact velocities can range from 1 to 16 km/sec for orbital debris and from 11 to 72 km/sec for meteoroids. Extensive research into the hypervelocity impact resistance of metals and metal alloys has been conducted in the past and has resulted in mathematical models relating the extent of damage to impact velocity, projectile/target geometry, and material properties of projectile and target that have been developed for these metallic materials. However, similar research on composite materials has been lacking. A summary of the results of such a study on a graphite fiber composite material is presented in this report.

The experimental data for this study was obtained using the Johnson Space Center small light-gas gun. The test samples consisted of 16-, 32-, 48-, and 96-lamina plates (6 by 6 in.) of a quasi-isotropic graphite-epoxy layup. (A quasi-isotropic layup was chosen to simplify the damage analysis.) The test matrix consisted of varying the lamina count and the projectile density for impact velocities ranging from 4 to 7.5 km/sec. An examination of the damaged specimens revealed the following observations:

Surface damage: All plates except the 96-lamina plates had visible front and back damage consisting of a crater and the peeling of the surface laminae about the area of impact. The direction of peeling was consistent with the direction of the fibers in the surface laminae. The fact that the degree and the zone of damage to the back of the plates was observed to be greater than that to the front of the plates strongly suggests that spallation is the major cause of damage to the back of the plates. The crater appears

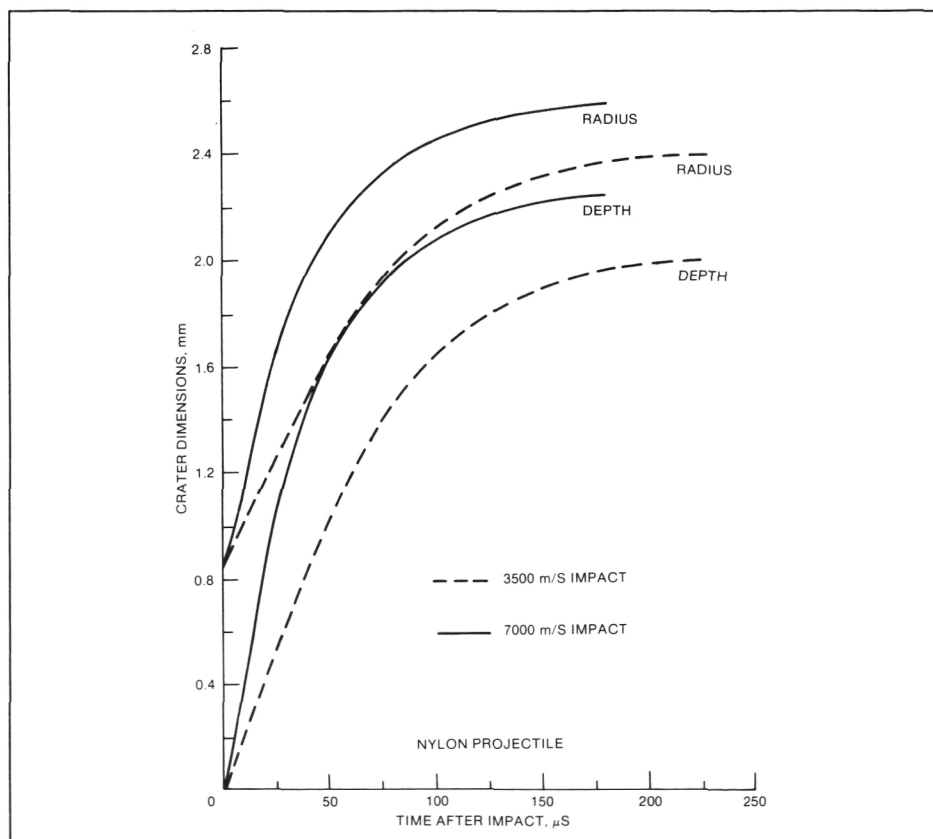
to be formed by the fragmentation of the laminae, unlike on a metallic plate where a crater is formed by the plastic flow of material. Complete breakthrough was experienced only with the 16-lamina plates.

Internal damage: An ultrasonic C-scanner was used to observe the extent of the internal damage. An elliptical area of severe damage about the impact point was observed for all plates. The plates were then sectioned through the center of the impact area, and the following damage was revealed:

1. A crater was formed on the impact side.
2. A small tunnel at the apex of the crater was formed because of shear plugging action (failure occurring when a projectile pushes a plate plug through the rear surface of the plate — caused by a shearing failure of plate material).
3. Large and multiple delaminations near the back surface were caused by the reflected tensile wave from the back surface (spallation).

A mathematical model for predicting the hypervelocity impact crater growth in a graphite-epoxy plate was developed (see plot), relating the time history of crater growth to the resistive pressure of the target material and the resistive pressure of the radial expansion of the projectile during the penetration process. The projectile and the target material are assumed to deform hydrodynamically during the process of penetration. The model shows that crater growth is insensitive to the mechanical properties of the material but is related to the impact velocity and the density ratio of the target and projectile materials. This relationship was substantiated by data from the shots using aluminum projectiles, where the damage was uniformly larger than that from nylon projectiles. Although the model is well substantiated by test data obtained to date, further verification and refinement of the model will be continued with more sophisticated laboratory diagnostic equipment.

Time history of the calculated crater growth in a 48-lamina graphite-epoxy plate.



**Measurement of Forest
Biophysical Properties Using
Microwave Scatterometers**

**PI: David E. Pitts/SN3
Gautam Badhwar/SN3
Reference OSSA 19**

Climatic changes which are unprecedented in the last 100 000 yr are predicted to occur if the amount of carbon dioxide in the Earth's atmosphere continues to increase and possibly doubles in the next century. For man to avoid a potentially catastrophic situation, better knowledge of the interaction among the atmosphere, the marine biosphere, and the terrestrial biota is needed.

During the last year, the Johnson Space Center has conducted research aimed at providing better global estimates of the interaction of forest canopies and the carbon budget through the use of satellite remote-sensing systems. Because cloud cover is prevalent over much of the world's forest, the use of active microwave systems has been emphasized. Improvement in global biogeochemical cycle models will require improved knowledge of the vegetation distribution over the Earth's surface and of the energy and mass fluxes between the vegetation and the atmosphere. The leaves and supporting structure (bole, limbs, and branches) of the forest canopy are key items for investigation because they represent the pool of carbon stored in the forest portion of the terrestrial biosphere and because they support the mechanisms that intercept the solar radiation and conduct photosynthesis.

To put this approach on a firm foundation, a helicopter-mounted C-band scatterometer was used to make soundings, i.e., to measure the backscattered power versus the range, in the forest canopies of black spruce, aspen, and jack pine over a northern Minnesota boreal forest area. Accurate measurements of canopy biophysical properties such as biomass and leaf area index were also made. The analysis of these data for high-density aspen shows that the total backscattered cross-section σ_0 , a measurement similar to that made by the Shuttle imaging radar (SIR) B instrument (L-band), does not change as the phenology changes through the season. Thus, the backscattered cross-section at C-band frequency cannot provide information about properties of the leaves such as leaf area index, a quantity of great importance in better understanding the role of the forest in the carbon cycle. Inversion of the sounding measurements, however, provided measurements of the canopy extinction and scattering properties. These properties have been found to be related to changes in canopy phenology and therefore are probably related to leaf biophysical properties. The implications of these results are likely to be profound for definitizing the scheduled SIR-C, the Canadian synthetic aperture radar (SAR), and the European C-band SAR (launch 1989). Much additional work in this direction prior to these launches is clearly needed.

Helicopter-mounted C-band scatterometer used to measure backscattering in northern Minnesota forests.



Space Flight Advanced Programs

Summary

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Office of Space Flight

Summary

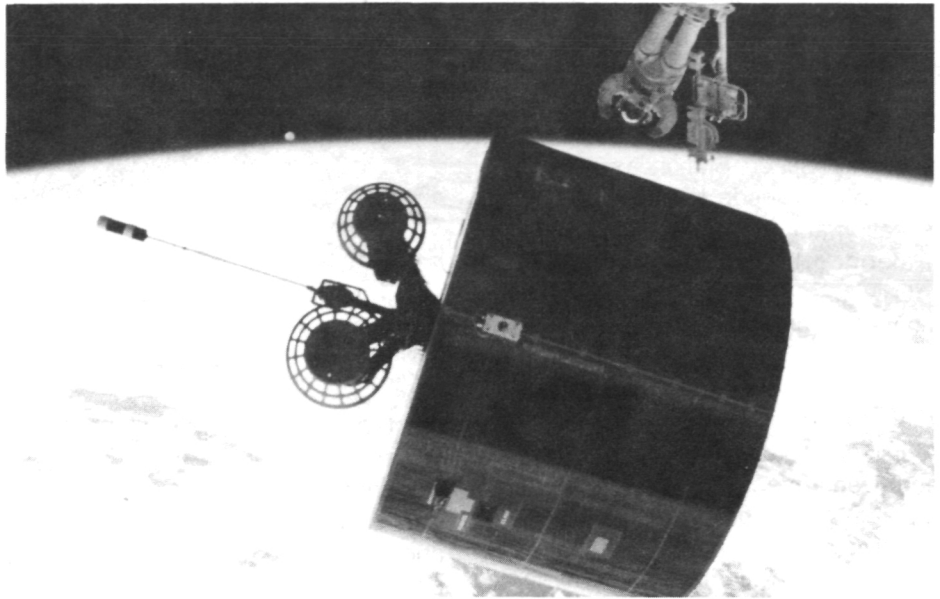
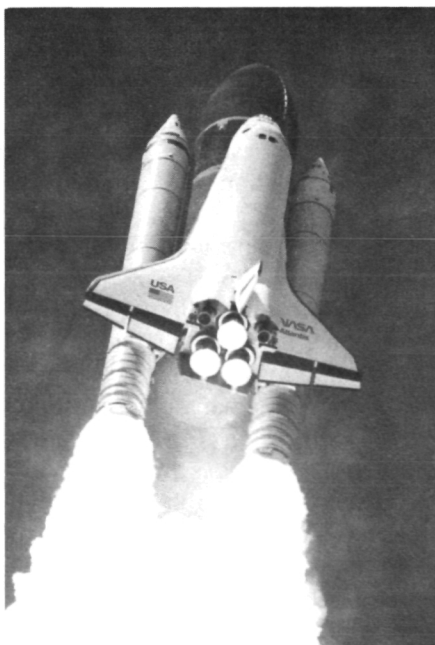
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Introduction

The Office of Space Flight (OSF) Advanced Programs activities are directed toward enhancing and expanding the National Space Transportation System (STS). The STS Program is approaching a fully operational status as evidenced by many significant achievements of this fiscal year (FY). The STS has successfully flown nine flights during FY 1985, including the first flight of *Atlantis* (Orbiter vehicle 104), the fourth Space Shuttle Orbiter. Several individuals from private industry and a U.S. Senator have served as crewmembers and gained insight into the potential research, development, and commercial opportunities in space.

More importantly, man's capabilities in space have been broadened. This extension has been demonstrated by

Lift-off of Orbiter *Atlantis* from launch pad 39-A, Kennedy Space Center.



Astronaut James van Hoften and the Syncom IV-3 communication satellite, which was retrieved, repaired, and redeployed during STS 51-L.

the successful retrieval and return of the Westar and Palapa satellites and the retrieval, repair, and redeployment of the Syncom F3 (Leasat 3) satellite.

A range of commercial satellite systems was successfully deployed including several from foreign countries (Morelos/Mexico and Aussat/Australia). Likewise, a number of successful flight experiments have been conducted, two of which were nurtured by OSF Advanced Programs and Flight Demonstrations sponsorship: an orbital refueling system (ORS) demonstration and a storable fluid management demonstration (SFMD). At the time of last year's publication, the ORS experiment (demonstration of fluid transfer capability) had just been accomplished. Subsequently, the information and experience gained from this experiment have provided a significant step toward enhancing satellite servicing capability

for the Orbiter and possible future mission activities. The SFMD is a facility that enables the investigation of fluid characteristics while in space. As a result of its successful demonstration, this facility will be used to perform a number of fluid management/low-g environment experiments.

Several other flight demonstrations are under development at the Johnson Space Center (JSC). The laser docking sensor (previously reported) will demonstrate the capability of providing accurate range, range rate, and bearing information to a target vehicle. The fluid transfer slosh control technique is designed to provide information to evaluate the slosh damping characteristics of a fluid in a low-g environment. Experiments such as these help to demonstrate the important potential of the Space Shuttle as a testbed for future space operations.

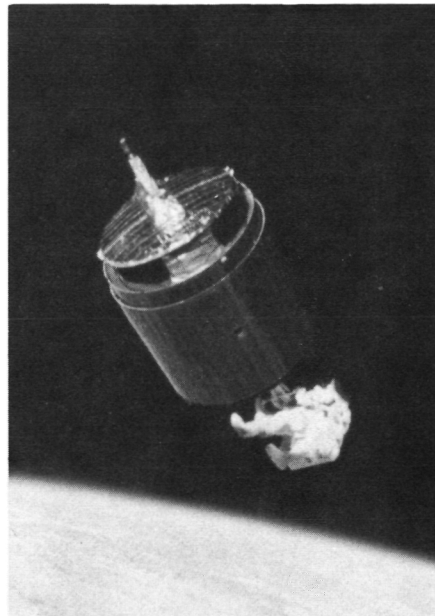
The JSC has the lead Center (level B) responsibility for the systems engineering and integration of the Space Station to achieve a capable and productive permanent presence in space. An additional complexity is time phase integration and the ensuring of compatibility with other STS systems in addressing capability beyond the initial Space Station. For this reason, as well as for the intrinsic value of foresight and perspective, JSC is examining the characteristics and requirements of future missions and associated systems. These studies include characterization of advanced transportation systems given the Space Station as an STS transportation node, in-house characterization and design studies of aerobraking orbital transfer vehicles (AOTV's), and identification of a logical lunar and martian exploration, development, and colonization program.

In a similar vein, the U.S. Government has initiated the Space Transportation Architecture Study involving both NASA and Department of Defense (DOD) members. The objectives of this study are (1) to determine the overall space transportation system architectures and future transportation and support systems for DOD and NASA that can simultaneously meet mission and operational requirements while substantially reducing total life cycle cost, (2) to identify the enabling technologies required for future space transportation architectures and to prepare an integrated plan to develop these technologies, and (3) to refine the transportation and support system concepts for mid-1990 architecture based on identified requirements.

The JSC has a number of support efforts within this activity ranging from mission requirements definitions and STS growth/enhancements studies to design and development of advanced vehicle concepts.

Space Operations

The fully operational Space Shuttle will soon have requirements for a wide range of satellite servicing equipment. Previous studies defined the require-



Astronaut Dale Gardner using the "stinger" to stabilize and retrieve the Westar VI satellite.

ments and provided conceptual design of various items of satellite services equipment. Some of this equipment is now available or under development, and the remainder consists of identified items for future development consideration. A continuing long-term goal is to baseline generic servicing equipment and to standardize servicing interfaces, and thereby minimize cost and operational complexity. Likewise, the use of automation and robotic techniques in space operations is becoming increasingly important.

Proposed requirements to conduct servicing operations on satellites, to perform contingency procedures, and to construct space platforms in hazardous or time-critical circumstances suggest the need for supplements to extravehicular activity by space crews. The operator and the computer, similar to the relationship of a craftsman and an apprentice, work together to accomplish the intricate operations that currently must be performed by the astronaut alone. In support of this concept, JSC has performed a general definition study of a telerobotic work system to determine whether it effectively meets maintenance servicing and construction requirements within

the overall space operations philosophy.

Another area of prime importance as on-orbit operations increase is the standardization of rendezvous and proximity operations procedures. The JSC is developing a proximity operations simulator to serve as a testbed as the Space Station and its companion orbital vehicles and systems mature.

Software Systems

An integral part of JSC's capability improvement effort is directly associated with the development and application of new engineering design tools. An example is the development of a high-speed interactive control system graphics work station. Analysis of various complex control problems can be markedly facilitated by the use of high-speed interactive graphics. A particularly advantageous application is control system analysis involving sophisticated dynamics such as large flexible space structures and multibody systems. With FY 1985 funds, a prototype work station has been purchased to support current analysis efforts and is being evaluated for developing future applications.

In the area of computational networking, efforts are being directed toward exploring the possibility of developing commonality and standardization of software and data systems. The purpose is to reduce not only the duplication of companion equipment but also the design and development cost of the computational equipment.

Orbital Propellant

A promising innovation for providing propellants to on-orbit systems is the scavenging of unused propellant from the Space Shuttle tanks. Current plans call for performing a scavenging feasibility flight experiment to demonstrate in-flight acquisition and transfer of cryogenic propellants from the main propulsion system and the external tank to a receiver tank in the payload bay. In conjunction with this activity is a separate study to determine the procedure by which propellant can be most efficiently transferred from two

independent bodies in orbit. A proposed method to take advantage of the orbital environment (gravity-gradient forces) is the use of a tether system. A number of technical issues associated with this concept, principally the effects of a pendulum type of slosh motion and the procedures for damping this type of motion, are currently under investigation.

Orbital Transfer Vehicles

With regard to orbital transfer vehicle (OTV) activity, JSC's expertise in entry systems and technology is being applied to the design and definition of a potential aerobraking flight experiment (AFE). This experiment is an attempt to provide a proper balance of objectives for basic technology development, system development, and capability demonstration. The entry configuration is a raked-off and blunted cone which should provide adequate aerodynamic performance while minimizing high-heating regions. Based on a point design consideration of an ultimate AOTV, this design is a contender for eventual application. More importantly, it can provide the empirical

data base required to advance sufficiently the state of the art in hypersonic aerodynamics, in aerothermodynamics, in thermal protection system performance, and in the guidance, navigation, and control characteristics of basic aerobraking maneuvers.

Supporting In-House Research

During the previous period, FY 1984, JSC conducted a significant study to understand the characteristics of a lunar base. In the process, significant interest in and an influential advocacy for manned Mars missions were discovered. Early in FY 1985, several cursory examinations of the manned Mars mission showed significant synergistic benefits for the consideration of an integrated Mars and lunar program. Thus, a brief study of manned Mars missions in order to look at an integrated long-range program for NASA became timely. To accomplish this purpose, the Los Alamos National Laboratory (LANL) proposed a joint 6-month activity with NASA to conduct a manned Mars study. This effort was principally targeted to update previous studies with current technologies and

systems and to determine the impacts to the anticipated year-2000 Earth-to-orbit systems and orbit-to-orbit systems, and to the growth of the Space Station. The study also investigated the impacts of advanced technologies and unique operational strategies. An executive summary will be published and distributed in January 1986. The working papers of the manned Mars study team will follow the executive summary and are expected to be published in the first quarter of the calendar year. Some of the key findings follow.

1. Current knowledge and predicted developments through the late 1990's in the field of space adaptation strongly indicate that a manned mission to Mars at the turn of the century must be an artificial-g configuration.

2. For conventional chemical propulsion, Earth launch masses will be between 1600 and 3500 metric tons and will require 2 yr for assembly and fueling at the Space Station.

3. Advanced technologies can greatly enhance the program by significant reductions in low Earth orbit (LEO) departure mass:

- a. Aerobraking: 20%-30% for conjunction-class missions, 60% for opposition-class missions

- b. Nuclear thermal propulsion: 50%-65%

- c. Nuclear electric propulsion: 50%-65%

4. Operational strategies utilizing extraterrestrial propellants may reduce LEO mass by:

- a. Lunar liquid oxygen, LEO launch: 30%

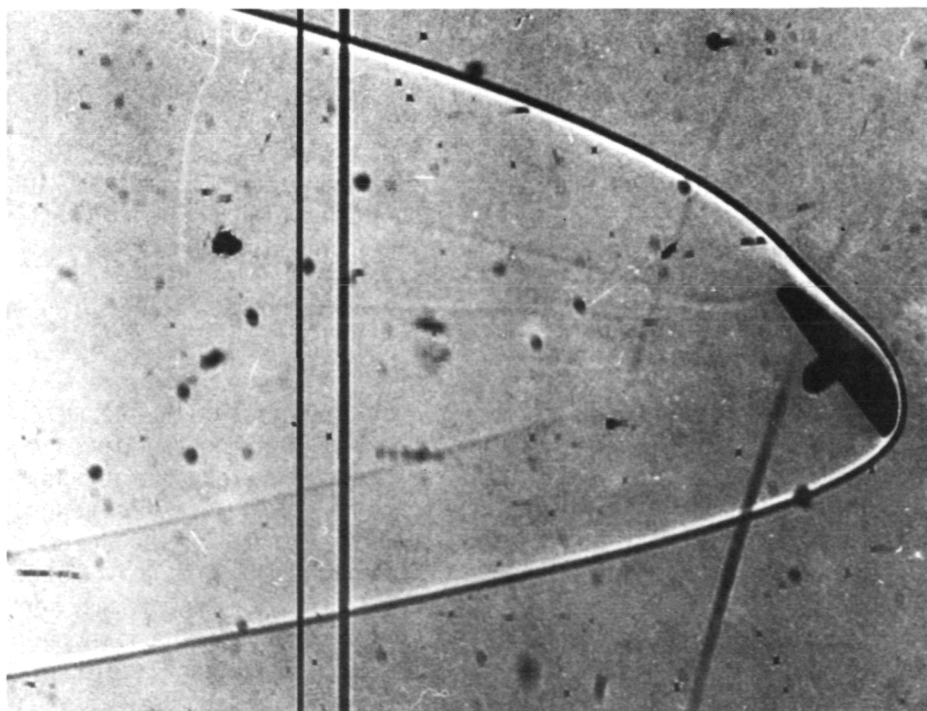
- b. Mars moon propellants: 30%

- c. Propellants available at both locations and Earth-Moon L-1 launch: 50%-70% (estimate)

In addition, such strategies as item 4c negate the need for a large trans-Mars injection (TMI) stage in LEO. The TMI can be accomplished with OTV-class vehicles when launched from L-1.

In support of the joint NASA/LANL study, JSC is conducting an in-house activity to develop a methodology that will permit the rapid conceptual design

Shadowgraph of an AFE configuration in the Ames Hypervelocity Free Flight Aerodynamic Facility at Mach 9.5 test conditions.





Conceptual lunar base.

of a Mars (or other planet, i.e., the Moon) surface infrastructure as well as to perform a few limited tradeoff studies. A report of these results will be available in the first quarter of calendar year 1986. A conceptual advanced lunar surface base is illustrated.

The JSC FY 1983 and FY 1984 activities resulted in a set of requirements for a manned OTV for geosynchronous Earth orbit (GEO) and lunar surface service. These requirements were given to an in-house study team for development of a vehicle concept. The team was further instructed to consider alternative structural designs to those proposed to date by commercial aerospace companies. These concepts are conventional propulsive stages with bolt-on aerobrakes and an aerosurface-to-total-vehicle weight ratio of approximately 35%. The in-house team chose an integral structural concept in which the structure was shared by all subsystems. That is, the tank and the avionics structural supports also support the aerobrake. This design resulted in aerobrake weight ratios of 17% for a conventional approach to the aeroshell and thermal protection system design. With some

design optimization, reduction of this weight ratio to 12%-13% or less should be possible. The resulting performance parameters for this stage are (1) GEO delivery of 13 500 kg, (2) GEO round trip of 7130 kg, and (3) lunar surface, two-stage LEO departure of 18 800 kg.

In all these activities, the major central theme beginning to emerge is that these advanced programs become far more practical if extraterrestrial resources are utilized. If the concept of carrying all necessary supplies had been used by the early American settlers, only the first 100 miles from the coastline would have been colonized. The use of extraterrestrial propellants for transfer vehicles also permits the opportunity to pursue many alternative strategies for the development of the space infrastructure. Thus, the next two fiscal years will be devoted to an integrated assessment of all potential GEO, lunar, and Mars missions and to consideration of many of the alternative strategies that utilize extraterrestrial resources.

In March 1984, the tethered satellite system (TSS) simulation working group, co-chaired by JSC and the Marshall Space Flight Center (MSFC), negotiated

an optional service with the National Space Transportation System Program Office that provides a real-time man-in-the-loop engineering simulation to demonstrate a manned deployment/retrieval of the TSS. The simulation was developed by JSC and validated by JSC and MSFC non-real-time TSS simulation reference data. This initial effort, referred to as phase I, was capable of retrieval from 1200 m and became operational in June 1985. The simulation has been utilized by JSC flightcrews in assessing TSS operational features and as a basis for recommending improvements to the TSS or as a tool to help determine design parameters. Phase II, which adds deployment and several technical refinements, was initiated in August 1985, and will be operational by December 1985.

The National Commission on Space (NCOS) is chartered to perform an overall review of our current space-related activities with the intent of formulating logical, achievable space goals for the 21st century. The JSC made a formal presentation to the NCOS and shared our technical views as to possible advanced missions. As space travel becomes more routine, and as NASA embarks on establishing a permanent Space Station, a better understanding of the principal characteristics of future human activities in space is becoming necessary. The characterization of advanced missions and associated system concepts should be adequate to provide perspective for programmatic and technological planning at all levels. Current cooperative efforts focus on missions beyond LEO and emphasize manned programs.

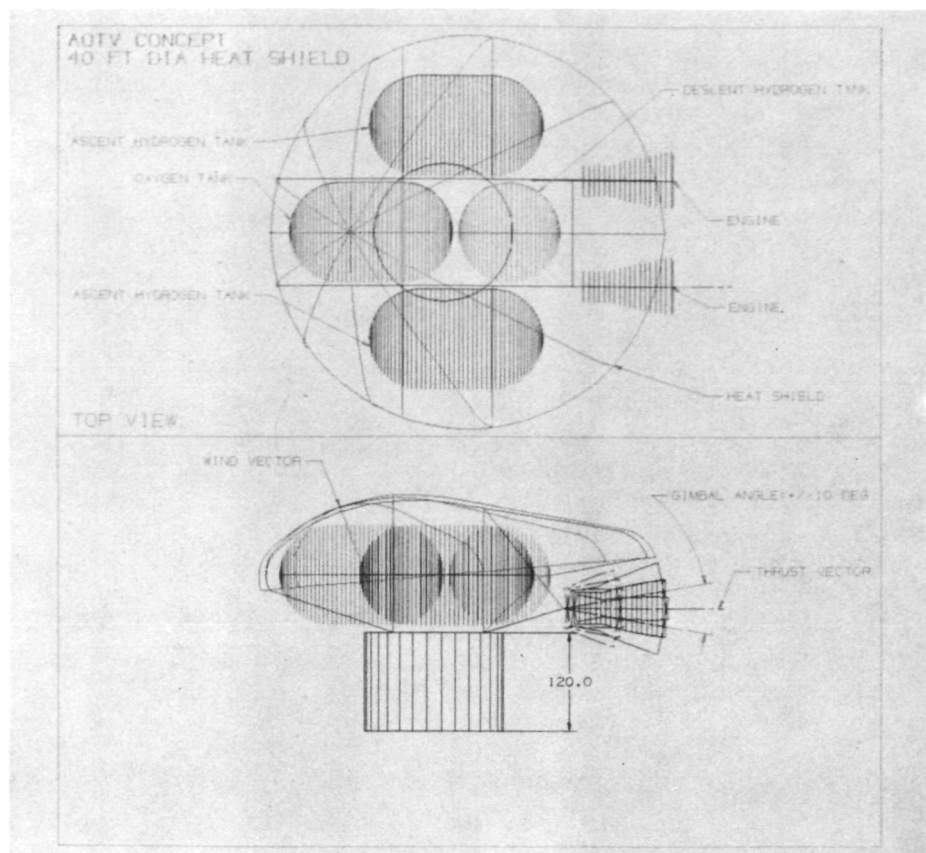
1. The utility and usage of GEO prompted an investigation of providing near-term manned service to GEO. Consideration of cryogenic H_2/O_2 LEO-to-GEO propulsion and of a two-man capsule designed to aerobrake back to LEO with docking interface capability and servicing equipment led to the conclusion that it would be difficult to achieve this capability from a single Space Shuttle launch. In addition, the stringent and unique

characteristics of such a system would be expensive. The use of a "line shack" (in-place radiation shielding, supplies, and equipment) at GEO relieved the transportation requirements somewhat but not sufficiently to make a single Space Shuttle mission launch straightforward.

2. An OTV concept for routine transportation from LEO to GEO with optional round trip manned capability was developed. This concept involved a space-based, space-assembled, reusable aerobraking system with cryogenic H_2/O_2 propulsion. The concept is both a propulsion and an aerobraking vehicle (with a thermal protective system capability essentially equal to current Space Shuttle tile) but does not carry the burdens of Earth launch and landing requirements. This vehicle would be supported by the Space Shuttle and based at the Space Station.

3. A permanently operated lunar base can be an evolutionary development from the LEO Space Station Program. Since the energy requirements for access to the Moon are only slightly greater than for access to GEO, the OTV concept was also considered as an element for support of manned lunar activity. The connecting link is an OTV capable of landing approximately 20 metric tons on the lunar surface. This capability allows the placement of Space-Station-like modules on the surface of the Moon and provides a nucleus for a permanent manned base.

4. Manned Mars mission scenarios such as flybys, excursions, outpost



A computer-aided-design-generated drawing of the JSC proposed AOTV configuration.

establishment, and colonization were developed, with different scenarios requiring varying vehicle design and associated capability requirements. In general, however, a manned Mars mission is a multiyear activity (1 yr for flyby, 3 yr for landing). The basic requirements include a significant enhancement in Earth launch capability, the use of the Space Station as a

transportation node, a high level of automation, and the development of approaches for dealing with both the radiation environment and life science issues. Mission performance can increase through the use of aerobraking, and future missions can benefit from advances in space propulsion and the use of extraterrestrial resources (e.g., lunar propellant).

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Space Flight Advanced Programs

Significant Tasks

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Satellite Services System

TM: Gordon Rysavy/EX
Reference OSF 1

The fully operational Space Transportation System (STS) must meet requirements for a wide range of satellite servicing functions, including capability for payload deployment and retrieval, payload support on sortie missions, and satellite support servicing within, or adjacent to, the Space Shuttle cargo bay. Potential satellite support requirements include (1) resupply of expendable items such as propellants or raw materials for processing, (2) checkout, maintenance, and repair, (3) reconfiguration of sensors, and (4) component exchange.

Previous studies defined the requirements and provided conceptual designs of various items of satellite services equipment. Some of this equipment is now available or under development, and the remainder consists of newly identified items for future development consideration.

The envisioned servicing equipment will be capable of multiple uses on Space Shuttle, Space Station, and orbital maneuvering vehicles and will provide services for satellites of wide-ranging varieties and orbital locations. This commonality will be achieved by maintaining standard interfaces, which are being developed in conjunction with the definition and development of the servicing equipment. Based on customer inputs through study contracts and workshops, concepts are defined and given testbed evaluations leading to flight hardware specifications.

The NASA goals are to baseline generic servicing equipment and to standardize the servicing interfaces and, thus, to allow satellite developers to consider servicing in their original design phase.

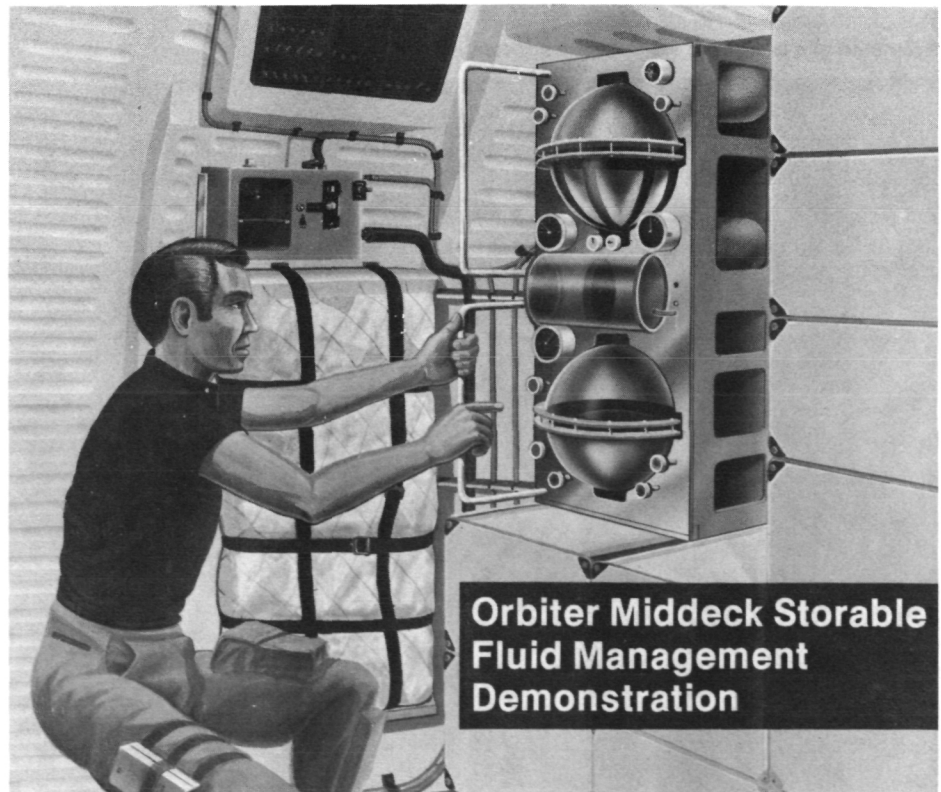
Major activities conducted in 1985 included the Space Shuttle flight of the storable fluid management demonstration (SFMD), a second satellite services workshop, and the publishing of an updated version of the tool and equipment catalog.

The SFMD flew as a middeck experiment on STS mission 51-C (January 1985). Its purpose was to investigate and observe the behavior of a liquid (water) within transparent plastic tanks in a low-g environment. Numerous tests involving a zero-g propellant management device (channels and baffles) were conducted to evaluate the filling and refilling, control of flow, venting, and pressurization aspects of a liquid in a low-g environment.

A workshop entitled "Satellite Services Workshop II" was conducted November 6-8, 1985, with extensive aerospace community participation. The objectives were to summarize accomplishments to date and to provide a forum for the exchange of information and the identification of key issues associated with on-orbit servicing of satellites.

An updated version of the EVA Catalog: Tools and Equipment, was published and released in November 1985. This catalog primarily describes extravehicular activity (EVA) tools and equipment used for the servicing of on-orbit satellites.

Orbiter middeck storable fluid management demonstration.



Orbiter Middeck Storable Fluid Management Demonstration

Telerobotic Work System Definition Study

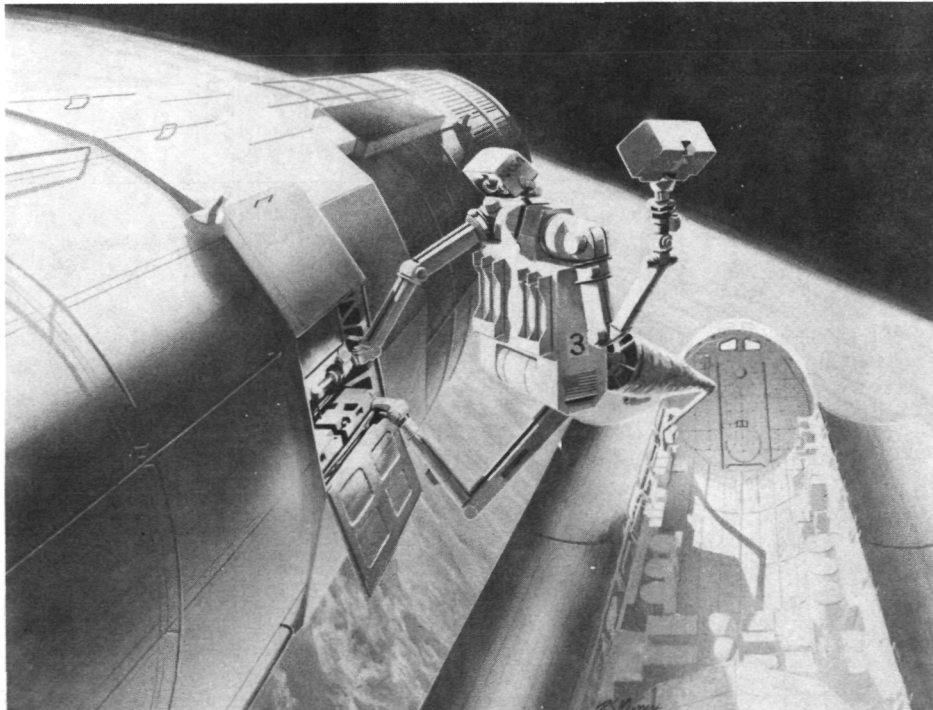
TM: Lyle M. Jenkins/EX
Reference OSF 2

The requirements to service and repair satellites from the Space Shuttle and to construct the Space Station have created the need for supplements and alternatives to extravehicular activity (EVA) by space crews. The use of automation and robotics in time-critical and hazardous operations is an important alternative capability for Space Transportation System operations. Definition of a system to meet servicing and construction requirements effectively must also fit within an overall space operations philosophy.

The examination of alternatives and supplements to EVA is based on compatibility with the EVA tasks to be performed. Remote operating systems to perform the tasks offer a reduction in hazard exposure and an increase in crew productivity and can be backed up operationally with EVA as necessary. The increase in productivity can be augmented by an evolution from teleoperation, to telepresence, to supervisory control, to a monitored robotic system. Sensors feed data about conditions at the work site to the operator's displays as well as to an artificial intelligence device. The operator and the computer work together to control dexterous manipulators to accomplish the intricate operations that currently must be done by EVA. The implementation of this approach is being studied in the concept of a telerobotic work system (TWS).

The TWS is a concept for applying teleoperation and telepresence techniques to space operations. The potential evolution of the TWS to allow more supervisory control and robotic capability is planned in the system architecture. Two parallel system definition studies of the TWS have been initiated as part of the development of an operational dexterous remote manipulation capability for the Space Shuttle Orbiter. The first study has defined an anthropomorphic configuration with two dexterous manipulator arms, a stabilizer arm, television cameras for vision sensors, a control station, and a system processor. The subsequent studies will add detail to the concept and define programmatic impacts. In-house work at the Johnson Space Center will concentrate on simulating the TWS. Computer simulation and readily available hardware will be employed to integrate system elements into a test-bed. Results of the activities will provide a basis for development of a flight system.

Illustration of a telerobotic work system concept.



Rendezvous and Proximity Operations GN&C System

TM: William L. Jackson/EH
Reference OSF 3

In recent years, a significant concern of NASA Headquarters has been the need to evolve a coordinated plan to provide integrated space operations for the numerous elements of NASA's space infrastructure. To date, many individual and often uncorrelated activities were in progress to develop the guidance, navigation, and control (GN&C) systems technology associated with rendezvous and proximity operations. The evolution of a cost-effective integration of the infrastructure elements required adherence to major design objectives and considerations, such as allowance for effective growth and employment of commonality and standardization among the elements of the infrastructure.

To this end, the first Rendezvous and Proximity Operations Workshop was conducted by the Johnson Space Center (JSC) and cosponsored by the NASA Headquarters Office of Space Flight (OSF) and Office of Aeronautics and Space Technology (OAST) in February 1985. The objectives of the workshop were to provide a forum for reviewing the current state of technology supporting rendezvous and proximity operations and to establish a focus for future technology and advanced development activities. The agenda was structured to address the following technical areas: space traffic control, mechanisms, man and/or machine operations, laser and radio-frequency technology, display and human factors, control, optical sensors, and data systems.

For JSC, a major task of the rendezvous/proximity operations GN&C system study project is managing the development of the proximity operations simulator (POS), which is one element of the Space Station GN&C testbed. The POS is a multiple-vehicle, digital, non-real-time, batch mode simulator

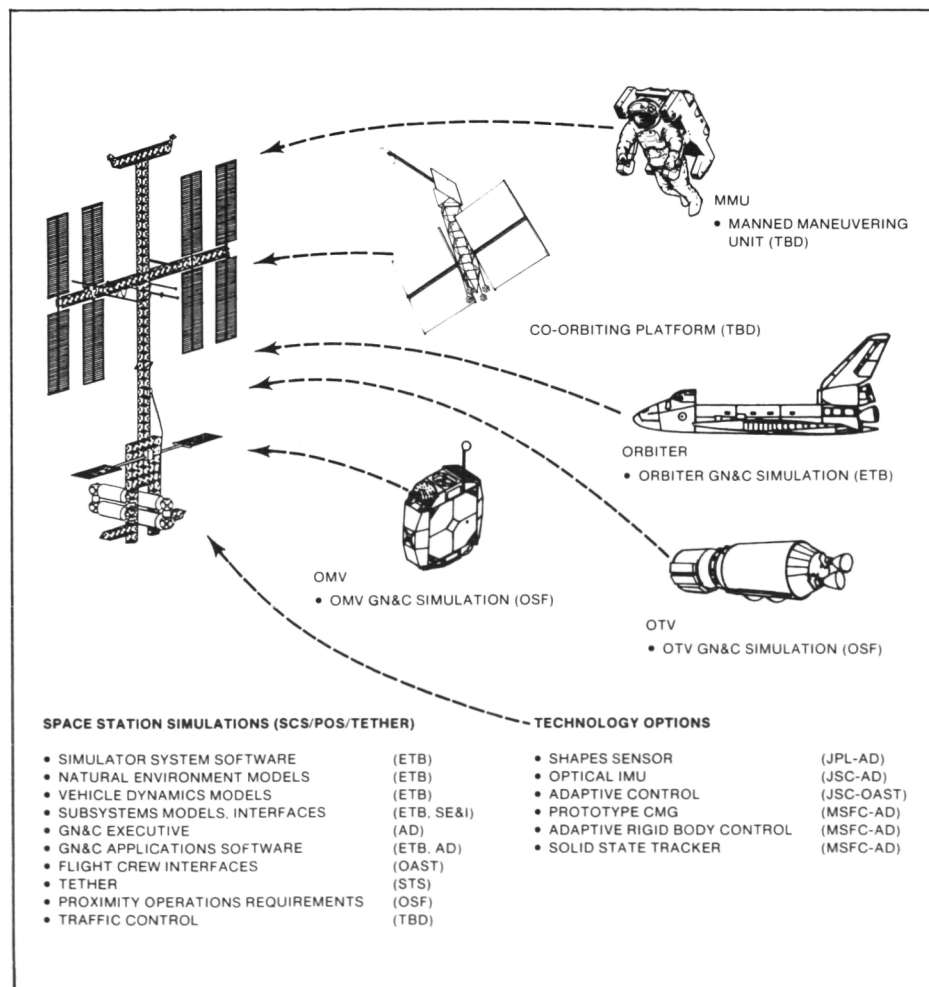
with high fidelity. It will include the Space Station, the Space Shuttle Orbiters, and other vehicles such as free flyers, the manned maneuvering unit (MMU), the orbital maneuvering vehicle (OMV), and the orbital transfer vehicle (OTV).

This simulator will be used in the definition, development, and integration of various vehicle elements in the space fleet. It will also be used for tradeoff studies involving multiple-vehicle interactions such as proximity operations, stationkeeping, traffic control, and approach and departure operations.

The POS code will retain all station control simulator (SCS) station code and will incorporate Space Shuttle code for guidance, navigation, and the GN&C subsystems. The POS Space Shuttle navigation code is being expanded to

include global positioning satellite navigation, and POS station guidance is being expanded to include NC-NH targeting on the station for the Space Shuttle. New three-degree-of-freedom (DOF) code with kinematic attitude is being developed for both the station and Space Shuttle vehicle dynamics and for some of the vehicle subsystems. The POS first article will not include attitude control. The Space Shuttle functional simulator six-DOF Orbiter models not included in the POS first article will be added later. The simulator system for POS is being expanded from the SCS system. The development of new POS code for the POS first article was scheduled for completion at the end of November 1985, and integration and testing of the POS first article is scheduled to be completed by the end of January 1986.

Proximity operations simulation.



Interactive Control System Graphics Work Station

TM: Edward T. Kubiak/EH
Reference OSF 4

Analysis of complex control problems can be markedly facilitated by the use of high-speed interactive graphics. Examples of particularly advantageous applications are control system analysis involving sophisticated dynamics such as large flexible space structures and multibody systems. Evaluations which might otherwise require a multitude of two-dimensional plots may be readily made with a single three-dimensional (versus time) graphical representation.

An effort has begun to develop a graphics work station which will ultimately allow the control system designer to rapidly assess the effect of his design iterations on a complex control problem. A prototype work station with an IMI-500 high-speed graphics device as a focal point was purchased in fiscal year (FY) 1985. This device, which uses stroke (as opposed to raster) graphics, was selected because of its high resolution (4k by 4k lines), its exceptional display processor update rate (32k vectors at 36 frames/sec), and its compatibility with existing Fortran driver programs. Additional capabilities include variable eyepoint viewing and screen segmenting, which permits simultaneous multiple views.

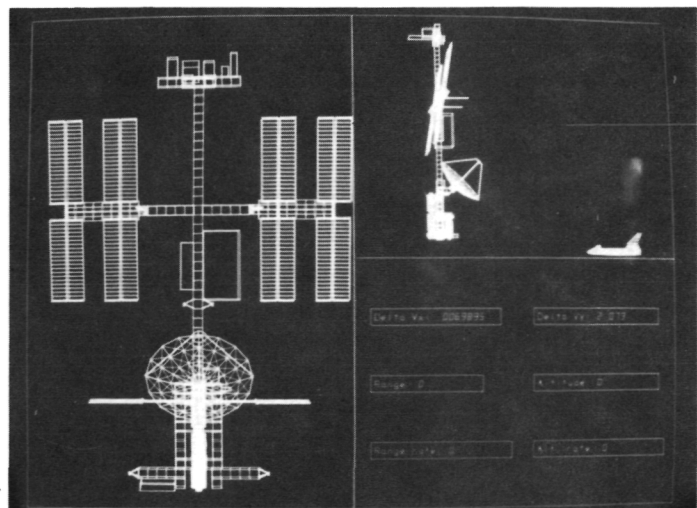
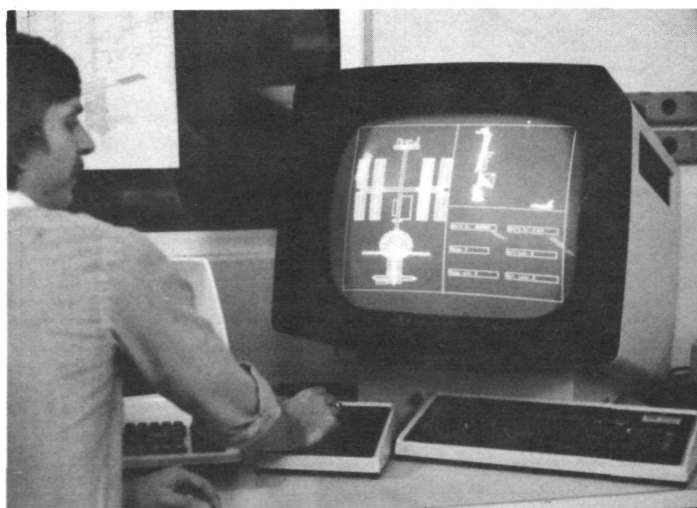
Graphics models currently installed in the work station include high-fidelity "wire-frame" versions of a Space Shuttle Orbiter, the manned Space Station, a remote manipulator system (RMS), and the Earth. Some models were newly developed, and others were obtained from various sources within the Johnson Space Center. An illustrative application example is the support provided on a separately funded task to evaluate loads and flight control stability during on-orbit operations when the gamma ray observatory (GRO) is attached to the Orbiter via the RMS. The task required, in chronological order, definition of candidate RMS positions, synthesis of the combined dynamics of the Orbiter/RMS/GRO, and evaluation of the candidate positions during on-orbit operations with respect to dynamic Orbiter/GRO clearances, GRO loads, and flight control stability. The work station was an invaluable tool, first, in establishing the viability of the initial candidate positions with respect to static clearances and RMS arm reach and, second, in making final evaluations based on time domain simulation analyses of the actual GRO loads and on RMS flexure-induced dynamic clearances and structural motion. For this application, the work station was not used in a purely interactive sense. That is, the data had to be transferred to the station after the run, because of

the lack of a direct link between the simulation mainframe and the station. However, the iterative process required to verify and identify acceptable arm positions was minimized.

The initial successful demonstration of the work station capability has led to a growing list of potential analysis patrons. Separately funded tasks expected to utilize the facility in FY 1986 include a task to optimize the location of the optical attitude sensors on the Space Station with respect to shadowing obscuration and a task to evaluate control system design with respect to tether dynamics for the upcoming Orbiter tethered satellite experiment. Additionally, as part of the work station development effort, a major activity will begin in FY 1986 to use the work station to synthesize a control system design for a large flexible spacecraft such as the Space Station. This design effort is to conclude in FY 1987 and will serve as the final confirmation of the operational capability of the work station.

Work station expansions planned for FY 1986 include the establishment of a communication network between the work station and in-house mainframe computers and the direct work station addition of microcomputer capability to accommodate smaller applications completely within the work station environment.

Example of an interactive control system.



Data and Software Commonality on Orbital Projects

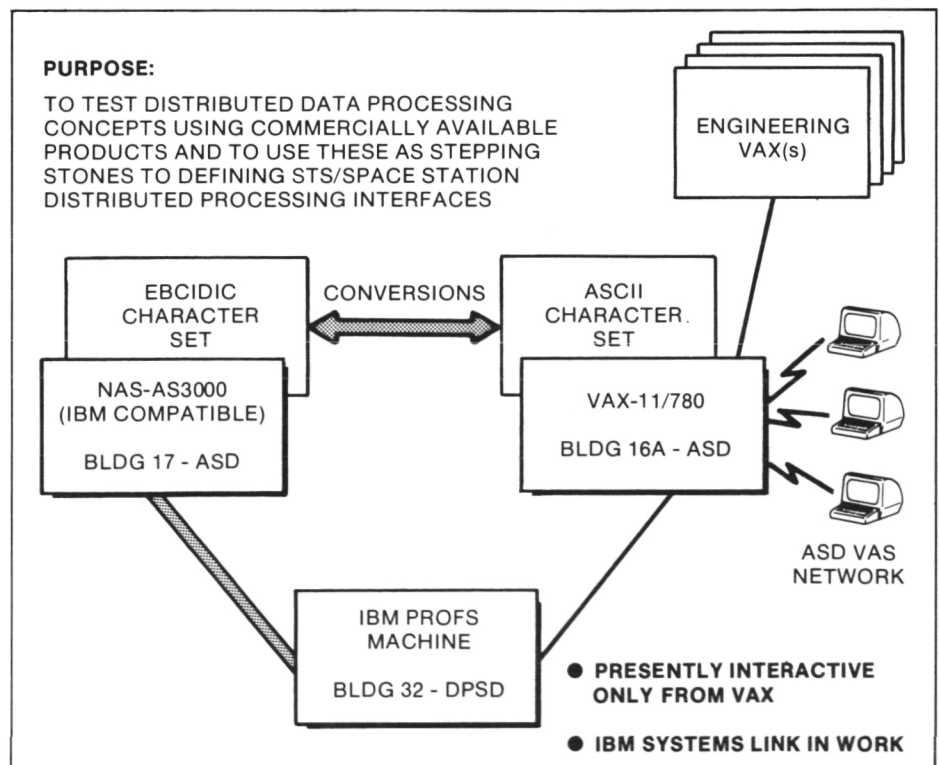
TM: Robert G. Musgrove/EH
Reference OSF 5

In the existing marketplace, communications network technology is mature, but technology for the high-level exchange of readily accessible data between dissimilar systems is not. This problem is compounded by the unique nature of flight avionics systems. The Johnson Space Center (JSC) has proposed a concept of test and verification through remote networked systems as a solution for future flight system data and software commonality. This concept provided for a commonality base that addresses the flight segment hardware and software, the ground segment development environment, and a rigorous testing approach. Although the Ada programming language will likely provide language commonality on future projects, the issue of systems connectivity from the ground-based development environment to the target flight computers must be thoroughly explored and tested.

Initially, JSC was to examine approaches for enhancing the life cycle longevity of flight avionics systems and for minimizing costs through data and software commonality across flight projects. One of the resulting outputs was to be a suggested set of standards and policies directed at achieving these objectives. The Ada language is intended to be a long-term solution for maintaining software commonality and is rapidly becoming the de facto standard for future programs. With this movement toward a software policy for future advanced systems, however, it was decided to redirect the research activities toward evaluating and testing system-to-system commonality.

An integral element of systems commonality is connectivity between systems to permit an accurate and efficient information and data transfer. Connectivity is much more than simple electrical interfacing; it is the true exchange, at a high level, of data and software applications. Fiscal year 1985 activities dealt with evaluating test distributed data processing concepts, using commercially available products, as stepping-stones to define Space Transportation System/Space Station distributed processing interfaces. Although elementary compared to the total integration of a Space Shuttle flight system, the task did serve to establish and demonstrate a connectivity baseline between dissimilar computing systems, VAX-IBM-CYBER.

Communications and networking.



STS Propellant Scavenging

TM: Donald E. Prevett/EP6
Reference OSF 6

Propellant scavenging from the Space Shuttle Orbiter has the potential to satisfy the cryogenic and Earth-storable propellant requirements of on-orbit users such as Space Station and space-based orbital vehicles. Unused Earth-storable bipropellants, monomethyl hydrazine and nitrogen tetroxide, can be provided from the Orbiter's orbital maneuvering system, and cryogenic liquid oxygen and hydrogen can be recovered from the main propulsion system and the external tank.

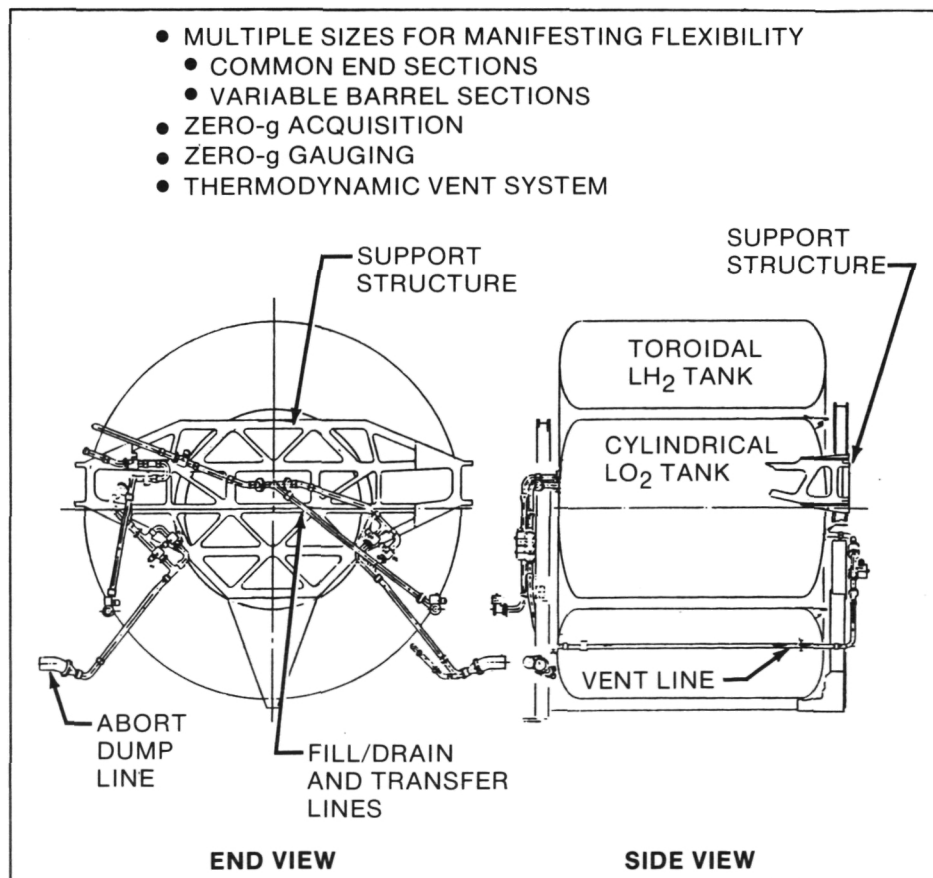
Phases I and II of the Space Transportation System (STS) propellant scavenging study (completed in 1984) indicated that cryogenic scavenging could be implemented with minimum impact to Orbiter operations by pre-loading special auxiliary tanks in the Orbiter payload bay as full as lift capability would permit. After main engine cutoff, residual propellant would then be transferred into any unused payload bay tank volume. This approach has the following operational advantages over other cryogenic scavenging schemes: (1) residual cryogenic propellant in the main propulsion system and the external tank is minimized by increasing the Space Shuttle load factor, (2) minimizing residual propellant reduces the time required for transfer into the payload bay scavenging tanks and therefore reduces the impacts to orbital insertion maneuvers and external tank jettison, and (3) transfer losses are minimized.

Earth-storable bipropellants for scavenging can be obtained by filling the orbital maneuvering system tanks above the level required for mission purposes (less than 80% for most Space Shuttle flights). As space and lift capability permit, supplemental tanks could be installed in the payload bay. Technologically advanced propellant pumps and ullage gas compressors would be required, in addition to zero-g acquisition devices.

Both Earth-storable and cryogenic scavenging scenarios envision the acquisition of multiple sizes of payload bay tank kits to allow selection of the most compatible size for a given Orbiter mission's primary payload manifest. Results indicate that scavenging can deliver propellant at lower cost than can dedicated Space Shuttle tanker flights (ranging from \$100/lb for 100 klb/yr to \$600/lb for 250 klb/yr, versus a forecast \$2000/lb for tankers).

Phase III of the study, scheduled for completion in May 1986, will refine the scavenged propellant availability and cost analyses for quantities as great as 500 klb/yr. In addition, possible configurations for a scavenging feasibility flight experiment will be assessed. The experiment would demonstrate the in-flight acquisition and transfer of cryogenic propellant to a receiver tank. One of the possibilities considered will be whether to use an existing tank or system or to build a special receiver tank. Subscale experiment sizing versus a full-scale demonstration test will also be considered.

STS propellant scavenging cryogenic payload bay tankage concept.



Tethered Orbital Refueling

TM: Kenneth R. Kroll/EP
Reference OSF 7

Future orbiting vehicles — such as a Space Station, satellites, and space-based propulsion stages — will rely on fluid resupply. To provide this function, a fluid facility that can acquire and transfer liquid will be required. This acquisition of liquid relies on the separation of the fluid phases, which can be randomly oriented in zero g. Zero-g liquid acquisition techniques can be complex, can have operational problems, or can have limited application to cryogenic fluids. During fluid transfer, the rise in the gas pressure must be overcome to prevent stoppage of the transfer. Techniques to overcome this problem either are for limited applications, are very complex, or can cause a contamination problem.

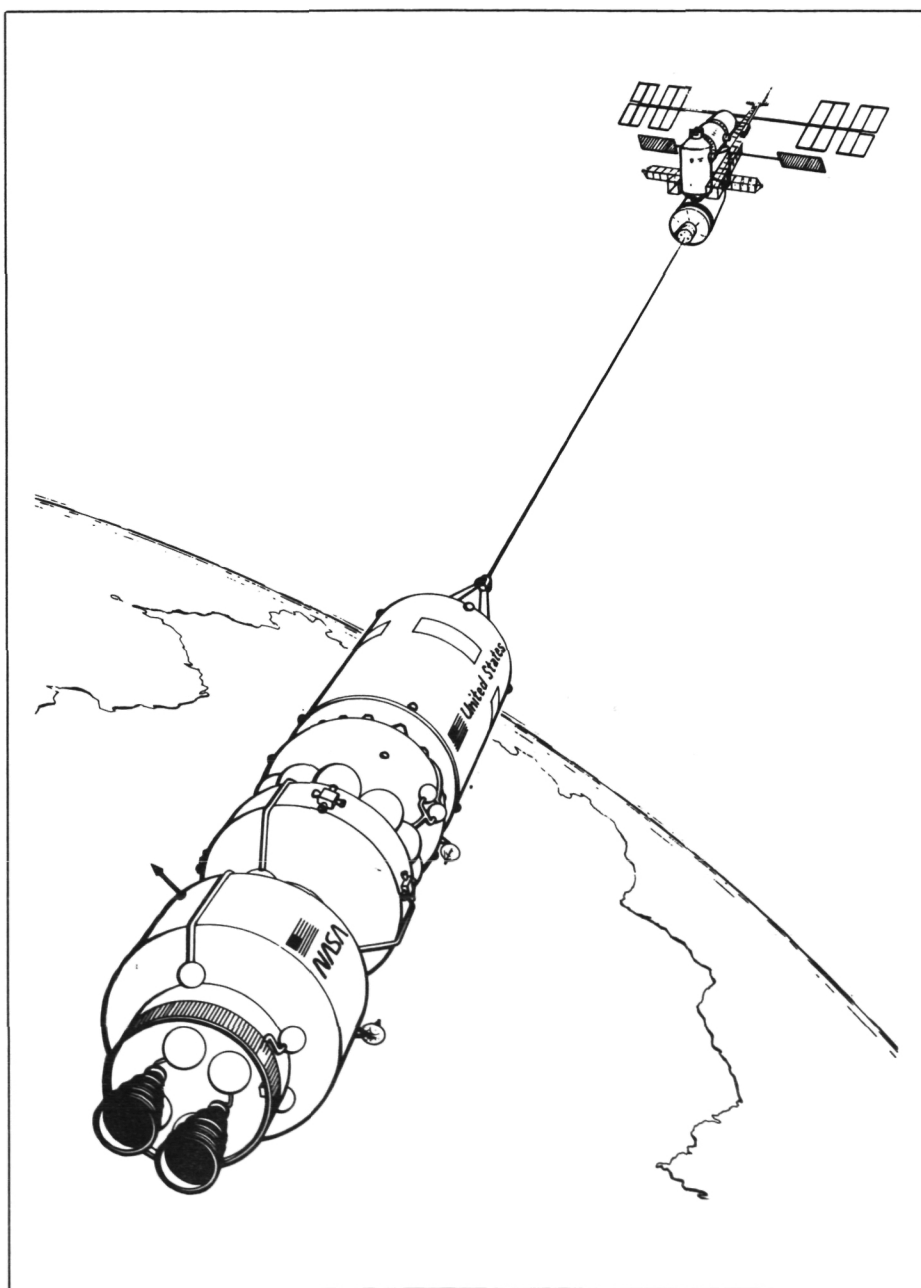
The orbital environment can be used to position liquid for acquisition in the supply tank and to position gas for venting from the receiver tank to the supply tank. A net force will result when the vehicle center of gravity (c.g.) is proportional to the vertical distance from that c.g., because the gravitational and centrifugal forces on an orbiting object cancel only at the c.g. A tether is a convenient structural means of providing a long distance and thus a greater force. A sufficient distance is required from the c.g. for this gravity-gradient force to overcome the liquid surface tension and to position the liquid. Although the liquid may have a preferential position, any lateral disturbance to the tank system can cause a pendulum type of slosh motion. Sloshing is the major fluid transfer problem for a tethered orbital refueling depot.

The slosh motion of the fluid in a tethered orbital refueling depot and an attached orbital transfer vehicle undergoing refueling has been examined. Single large disturbances to the fluid are rare and primarily result from

changes in the system, such as the docking of a Space Shuttle to the Space Station. For a single large disturbance, the best course of action is to provide a long tether and to shape the tanks to minimize the resulting maximum slosh angle. However, the additive effect of multiple disturbances must be avoided. Adding ring baffles in the tank can provide sufficient slosh damping to reduce the acceptable time between multiple disturbances.

The major issue with use of the tethered orbital refueling depot will be its operational difficulties. The depot can either be deployed every time it is required or be permanently deployed. The deployment operation will be complex. Permanent deployment has problems with providing microgravity at the Space Station, with transfer of vehicles to the depot, and with tether breakage. These operational difficulties are currently being evaluated.

Concept of orbital transfer vehicle refueling facility tethered to Space Station.



Orbital Transfer Vehicle GN&C System Technology Requirements

TM: Gene McSwain/EH4
Reference OSF 8

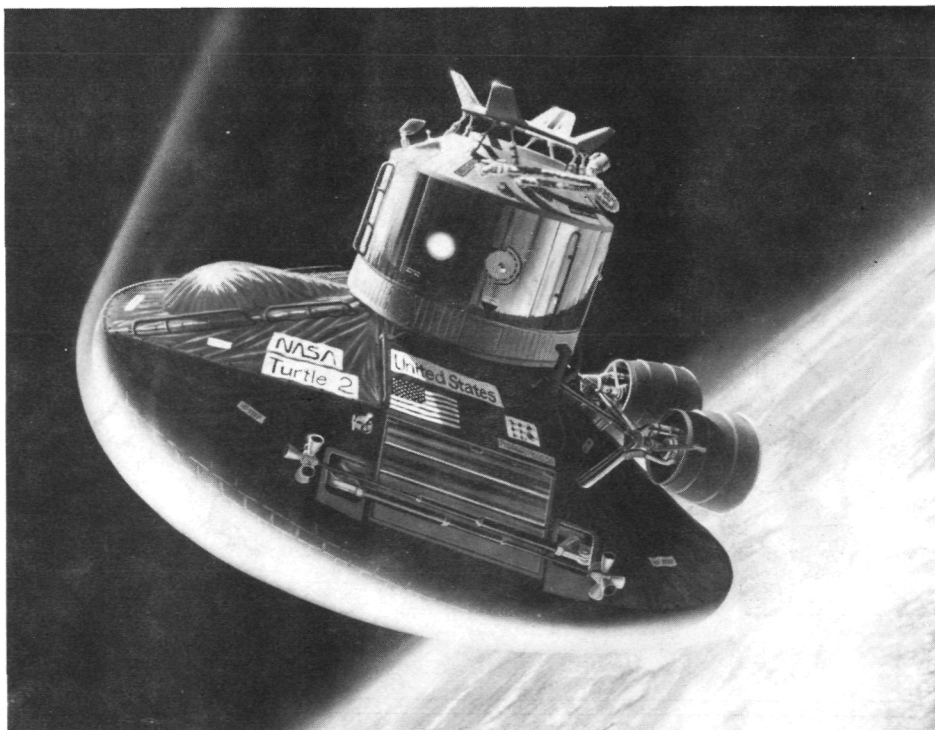
A reusable orbital transfer vehicle (OTV) is being considered as a logical extension of the Space Transportation System. The OTV is to be space-based and will employ aerobraking during its return to low Earth orbit. The OTV guidance, navigation, and control (GN&C) system will be characterized in the context of the Space Transportation System and expendable upper stage experience to maximize the technology transfer between NASA programs and to capitalize on lessons learned from past programs.

The approach is to develop aerobraking guidance requirements for both a lifting and a drag modulation brake. Currently, either brake configuration is a viable contender for use on the operational OTV. Since the guidance algorithm is critical to the specification of the navigation and control requirements, particular attention is to be focused on sensitivity to trajectory dispersions, navigation errors, vehicle aerodynamic properties, and control authority. A conceptual definition of onboard guidance and targeting for all powered flight phases including after aerobraking burns will be developed. Additionally, support of the planned aerobraking flight experiment (AFE) (reported separately) will be provided in the following areas: (1) development of guidance and navigation algorithms, (2) evaluation of navigation techniques and accuracy requirements of the AFE mission, (3) evaluation of the Honeywell 700-3 ring laser gyro as a candidate inertial navigation system for the AFE, and (4) analysis of atmospheric density variations that might affect the OTV or the AFE aerobraking performance.

Progress during fiscal year 1985 included the following:

1. Development of a technique for in-flight alignment of an inertial measurement unit (IMU) using a non-colocated star tracker. An example of this use might be the alignment, using the Orbiter's fixed star tracker, of an OTV IMU while the OTV is onboard the Orbiter.
2. The analysis of atmospheric density dispersions at altitudes where an OTV aerobraking maneuver would take place.
3. Detailed evaluation of the Honeywell 700-3 ring laser inertial navigation system for use in the AFE.
4. Development of a powered flight guidance algorithm for the AFE solid-rocket direct-insertion burn.

Proposed concept of a reusable orbital transfer vehicle.



GN&C Flight Software for the Aerobraking Flight Test

TM: Gene McSwain/EH4
Reference OSF 9

An aeroassisted orbital transfer vehicle (AOTV) would employ an aerobraking maneuver in the Earth's atmosphere in lieu of a propulsive maneuver to return from geosynchronous orbit. The use of aerobraking can significantly increase the payload capacity of the orbital transfer vehicle (OTV), provided the weight penalty of the aerobrake is not excessive. Current estimates for conventional structural materials indicate that an adequate aerobrake could be designed with a weight penalty of no more than 17% of the dry weight of the vehicle. This addition would result in a 76% increase in payload weight delivered to geosynchronous orbit when compared to an all-propulsive vehicle design.

The aerobraking maneuver would take place in the upper atmosphere at speeds as high as 33 800 ft/sec. Because current knowledge about the chemical, aerodynamic, and aerothermal environment of the upper atmosphere is limited, an aerobraking flight experiment (AFE) has been proposed to provide critical environmental data in the areas of nonequilibrium radiative and convective heating, wall catalysis, and aerodynamics that cannot be explored in ground test facilities. The design and development of the AFE is the joint responsibility of four NASA field centers: the Marshall Space Flight Center (MSFC), the Kennedy Space Center, the Langley Research Center, and the Johnson Space Center (JSC). The JSC has the responsibility for the development of the rigid aerobrake subsystem and the guidance, navigation, and control (GN&C) software requirements. This paper addresses the approach and progress made in the development of the GN&C software requirements for the AFE during fiscal year (FY) 1985.

The approach taken for the development of the GN&C requirements is to minimize cost by making maximum use of existing

Space Shuttle-related tools and expertise. Current activities involve the design and analysis of a GN&C system for all flight phases of the AFE vehicle and the development of an engineering simulation to test the GN&C design functionally.

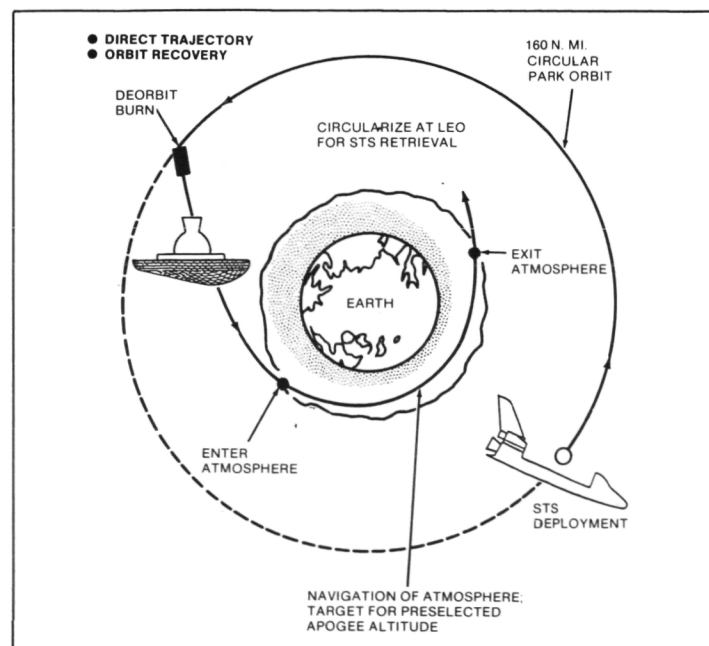
The baseline AFE vehicle proposed by MSFC consists of a rigid aerobrake to be provided by JSC and a carrier vehicle to be provided by MSFC. The rigid brake is a 14-ft-diameter raked-off and blunted elliptical cone with a cone half angle of 60° and a rake angle of 73° . This configuration provides a lift to drag ratio of 0.3 at a trim angle of attack of 17° . A STAR 48 solid rocket motor (SRM) will provide a sufficient change in velocity to insert the AFE into an orbit that simulates a return from geosynchronous orbit.

The AFE will be deployed by the Space Shuttle in a 160-n. mi. circular orbit. After a 45-min coast phase, the STAR 48 will be ignited at a burn attitude of approximately 40° below the local horizontal plane to provide a near-impulsive delta velocity increment of 8000 ft/sec. Following burnout of the STAR 48, a short reaction control system (RCS) trim burn will correct for any SRM burn dispersions. After a 1-min coast, the entry interface conditions

are achieved (altitude of 400 000 ft, relative velocity of 32 464 ft/sec, and relative flightpath angle of -4.2°). During the atmospheric braking phase, the vehicle will be rolled about the relative velocity vector to provide the proper amount of in-plane lift required to achieve the desired atmospheric exit conditions. Bank reversals will be utilized to avoid excessive out-of-plane velocity buildup during the 12-min aeropass. At apogee following the aeropass, the RCS will be fired to raise the perigee high enough to avoid reentering the atmosphere and to provide the proper phasing for rendezvous with the Orbiter. The AFE will be retrieved by the Orbiter remote manipulator system, 13 hr and 35 min after deployment.

Progress during FY 1985 included the following: (1) the analysis and model development of atmospheric density disturbances, (2) the conversion of an existing six-degree-of-freedom Space Shuttle engineering simulation to the AFE problem, (3) the update of the AFE engineering simulation to reflect the baseline AFE configuration and the design reference mission, and (4) the development of a preliminary GN&C flight software requirements document.

Aerobraking flight experiment baseline mission profile.



Manned GEO, Lunar, and Mars Mission Analysis

TM: Barney B. Roberts/ED
Reference OSF 10

To provide the guidance for a logical, rational, and properly phased development of the Space Station, of Earth-to-orbit vehicles, and of orbit-to-orbit vehicles and for the purposeful development of advanced technologies, several advanced mission activities were continued during fiscal year (FY) 1985.

The FY 1985 activities were accomplished through a combination of in-house civil service resources, contracted support, and cooperative efforts with local universities and other government agencies. The major sponsor of these funded activities was the OSF Advanced Programs office; however, several offices supported the university program, and the Chief Engineer sponsored the Mars study in conjunction with the Department of Energy. The principal activities were:

1. NASA/Los Alamos National Laboratory joint manned Mars program study and workshop on June 10-14, 1985
2. A Johnson Space Center (JSC) study on manned Mars surface elements and tradeoff options
3. Conceptual design of a geosynchronous Earth orbit (GEO)/lunar orbit transfer vehicle
4. Advanced mission studies
5. Lunar Base Modeling Workshop — August 26-30, 1985, hosted by the Large-Scale Programs Institute and sponsored by JSC and the RGK Foundation

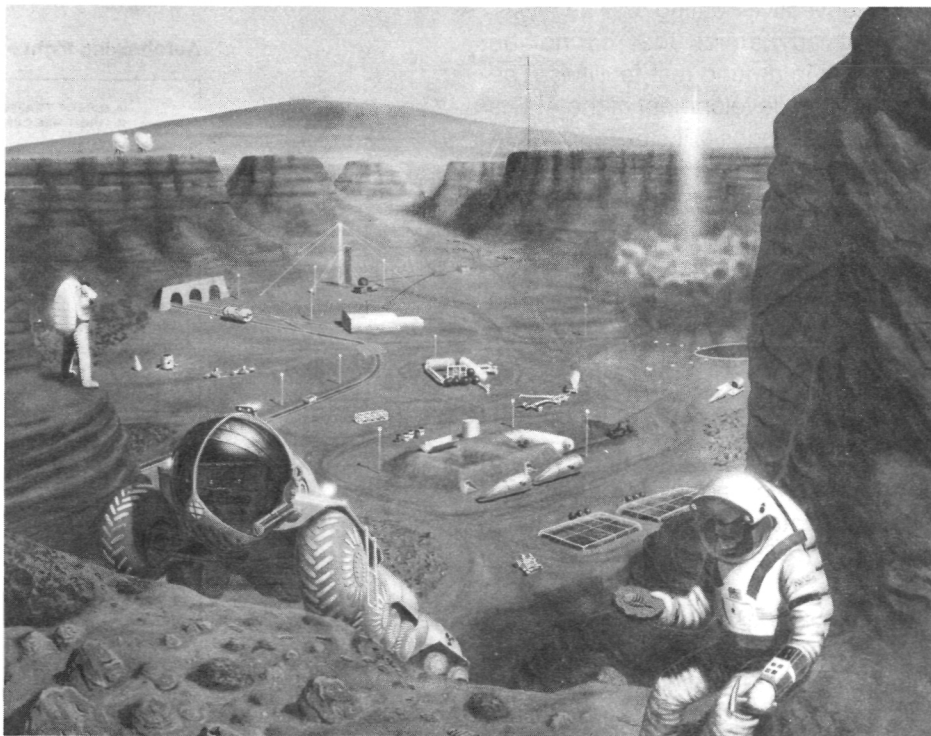
The following products are significant accomplishments from the advanced mission studies that were executed to support these activities. Some are completed, and others are still in process. Only the completed contracts are reported.

Lunar Base Methodology Development: An activity was begun on the development of a strategic planning model for advanced missions. A workshop held on August 26-30, 1985, to develop the framework for the methodology resulted in the definition of a methodology that can be developed to perform conceptual definitions of a lunar base. The inputs are the requirements for the base, and the outputs are the required elements of the base, the cost, scheduling parameters, and a collection of other cost and benefit parameters. This tool should be useful in strategic planning for any future space program. The lunar base was chosen as an example for tool development; however, the structure is to be general enough for future application to any program.

Advanced Space Transportation Systems Support: A significant contracted activity was conducted to support the definition of future space transportation systems. The results show that conventional spacecraft designs require masses in low Earth orbit that border on impracticality and that the key technologies with the highest leverage on the transportation system are (1) the development of the capability for in situ propellant production using extra-terrestrial resources, (2) the use of aerobraking vehicles wherever possible, and (3) the development of advanced high-performance propulsion systems.

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A possible martian exploration effort with base elements such as greenhouses, habitat and laboratory modules, and transverse vehicles.



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OAST 2	Advanced Radiator Flight Experiment Funded by: Space Flight Systems Technology (UPN-542) Technical Monitor: J. Gary Rankin/EC2 Task Performed by: Grumman Aerospace Corporation Contract NAS 9-15965
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